

**EXPERIMENTAL ENHANCEMENT OF
SINGLE SLOPE SOLAR STILL**

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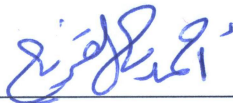
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IN THE NAME OF ALLAH, THE MOST BENEFICIENT, THE MOST MERCIFUL

Proclaim! In the name of thy Lord and Cherisher, Who created man, out of a (mere) clot of congealed blood. Proclaim! And thy Lord is Most Bountiful, He who taught (the use of) the pen, taught man that which he knew not. Nay, but man doth transgress all bounds, in that he looketh upon himself as self-sufficient. Verily, to thy Lord is the return (of all). (Surah 96: Al 'Alaq, 1-8)

All praises are due to Allah (SWT), the Cherisher and Sustainer of the worlds, none is worthy of worship but Him. I am sincerely thankful to Him for His kindest blessings on me and all the members of my family. I ask for His blessings, mercy and forgiveness all the time. May the peace and blessings of Allah be upon his dearest prophet, Muhammad (Peace Be upon Him).

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THESIS ABSTRACT

NAME: Mohammed Aves
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The importance of desalination has grown many folds since the tremendous industrial and population growth in areas where fresh water supply has become inadequate. Man-made solutions to the problem lie in desalting sea water and inland brackish water. In this study, the effect of water depth and the slope of the cover on the productivity of a single slope solar still are studied experimentally in King Fahd University of Petroleum and Minerals Campus area. The stills were constructed using galvanized iron with a base area of 1 m x 0.5 m with different condenser cover angles 25°, 30°, 35° and 40°. Temperatures of glass cover (inside and outside), temperature of seawater inside the still, atmospheric pressure, wind velocity and ambient temperature were recorded continuously and distilled water was measured for each hour. To obtain extra solar energy, four external mirrors (1 m x 0.5 m) were used on four sides of the still and the effect of external mirrors on the productivity was examined.

ABSTRACT (ARABIC)

الاسم: محمد أويس

العنوان: تعزيز تجريبي لتقطير المياه بالطاقة الشمسية

التخصص: هندسة الطيران و الفضاء

التاريخ: 2011 م ، 1432 هـ

لقد نمت كثيراً أهمية تحلية المياه منذ النمو الصناعي و السكاني الهائل خاصة في المناطق التي تشح فيها المياه العذبة. و هناك بعض الحلول التي قام بها الإنسان لحل مشاكل تحلية المياه باستخدام مياه البحر و المياه الداخلية المالحة . هذه الدراسة التجريبية تبحث تأثير عمق المياه في أجهزة التقطير و ميل الأسطح الزجاجية للأجهزة على كمية الانتاجية للماء المقطر بالطاقة الشمسية . و قد تم بناء مقطرات ترشيح باستخدام الحديد المغطى وقاعدة مكونة من 1 متر في 0.5 متر مع أربع زوايا ميول مختلفة (25 درجة ، 30 درجة ، 35 درجة و 40 درجة) . و قد تم قياس درجات الحرارة للغطاء الزجاجي (بالداخل و الخارج) ، و درجة حرارة مياه البحر بداخل المقطر ، و الضغط الجوي ، و سرعة الرياح و درجة الحرارة الخارجية المحيطة و التي سجلت جميعاً بشكل مستمر لكل ساعة . و لزيادة الطاقة الشمسية تم استخدام أربعة مرايا خارجية (مقياس 1 م * 0.5 م) على أربعة جوانب و تم قياس تأثيرها على إنتاجية الماء المقطر .

CHAPTER 1

INTRODUCTION

1.1 Overview

The water sources like lakes, rivers and the pumped out ground water are the main resources for domestic, agricultural and Industrial usage. 71% of Earth Surface is covered with water of which 97% is in the oceans and the remaining 3% of water is fresh water. Of this 3% water, 2.4% is permanently frozen in glaciers and at the polar ice caps. The increasing demand of water with depleting water resources available made us to think about various methods to purify Sea-water and brackish water.

Sea water contains approximately 50 simple substances of which chlorine amounts to 55%. The salinity of sea water varies/changes from one sea to another, approximately salinity is around is 35 gm/l. Another non-drinkable form of water is brackish water. The salinity usually varies between 1 and 33 gm/l. Brackish water are classified depending on salinity as Slightly brackish having a salinity between 1 and 3 g/l, Moderately brackish having a salinity between 3 and 10 gm/l and High brackish with salinity above 10 gm/l.

Distilling water for drinking purposes is especially crucial in semi arid or arid countries where surface water is limited and groundwater is saline. Various methods of desalination like Reverse Osmosis (RO), Multi-stage Flash (MSF), Multi-effect

distillation (MEF) and Electrodialysis have been developed. These desalination units require fossil/electric energy sources. The cost of these energies has risen by a factor over the past few years and further more technical maintenance problems made these types of methods inadequate.

Although extensive research into water desalinization is taking place, simple solar stills are appropriate for simple household use in developing countries. The design is inexpensive and easy to construct, there are no moving parts, which simplifies maintenance, and only the sun's energy is required for operation. Solar stills can operated in the passive mode where solar energy heats the saline or brackish water directly, or they may be operated in active mode where the salty water could be heated or preheated by solar collectors, before it is evaporated in the still basin.

1.2 Solar Still

A Solar still is a simple device with an airtight basin, covered with transparent material like glass or plastic. It converts salt/waste water into drinking/potable water. The basin is internally coated with black color/material to absorb solar energy which is transmitted and diffused through the top cover. The water in the basin heats up and evaporates inside the still. The vapors reach the inner surface of top cover and condense into pure water. The water runs down along the cover bottom surface due to gravity and is collected in a tray.

The energy exchange mechanism is shown in the Figure 1.1. The Solar radiation both direct and diffuse falling on the still is absorbed by the blackened base. At glass surface, water surface and to a small extent at the base, energy is lost due to reflection. Thermal losses in the form of leakage of water vapor also occur.

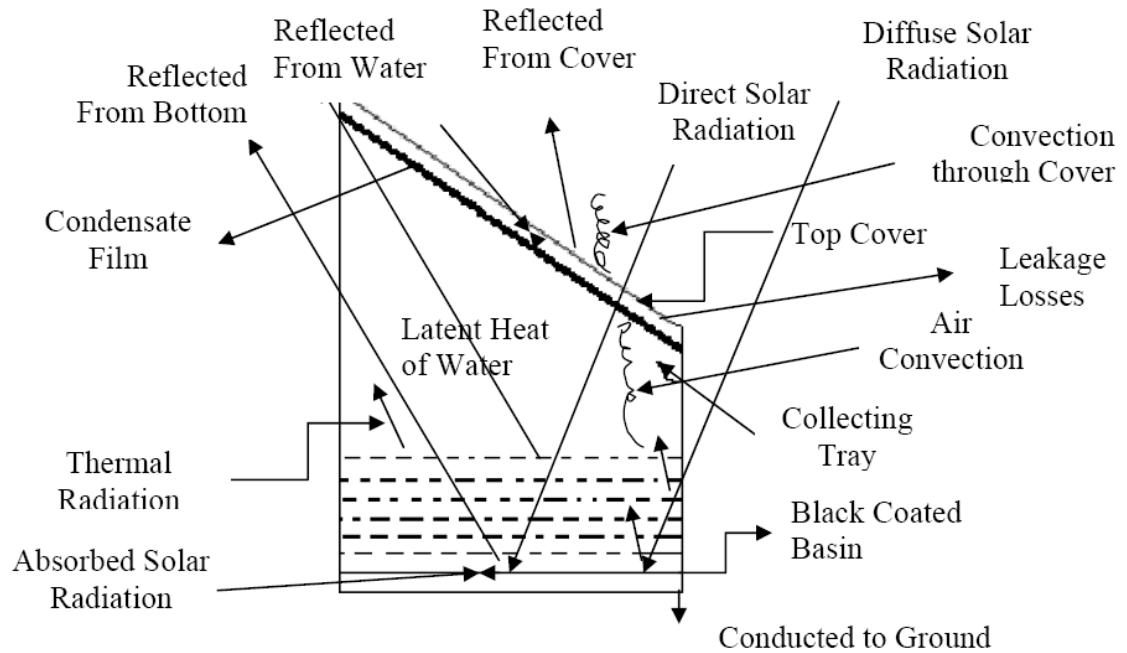


Figure 1.1: Energy Flow Diagram of a basin type solar still

1.3 Problem Statement

The Solar radiation both direct and diffuse is utilized for the production of distilled water. The output obtained by the simple single slope solar still is low because of energy losses. The main components of the energy loss for a typical set of parameters [1] are as follows:

S. No.		% of Solar Radiation
1.	Evaporation of distillate (efficiency)	31
2.	Ground and Edge Heat losses	02

3.	Solar radiation reflected from still	11
4.	Solar radiation absorbed by cover	05
5.	Radiation from basin water to cover	26
6.	Internal Convection	08
7.	Re-evaporation of distillate and unaccounted for losses	17
		100

Table 1.1: Components of the energy loss

Though lot of productivity enhancement methods were applied, the problem of energy losses is not yet solved completely. Thus, there is a need to study the factors affecting the still productivity without increasing the cost of construction and maintenance.

This thesis deals with the problem of energy losses in a single slope solar still and the factors affecting them. Different enhancement techniques are applied in order to suggest measures for improvement in the performance of solar still.

1.4 Thesis Objective

The objective of this thesis is to study different parameters affecting the solar still productivity experimentally. The effect of enhancements like External Mirrors from four sides of the still on the output will also be studied. A step-wise procedure to achieve this framework can be summarized under following objectives:

- Literature review of existing methods for experimental enhancement of output of the still.
- Design, test and collect the data of the solar still with different water depth, angle with and without enhancements like External Mirrors.
- Study and analyze the data collected.

1.5 Thesis Organization

The outline of this thesis is as follows. Chapter 1 provides an overview of the main areas of focus by outlining the objectives. In Chapter 2, study of the existing techniques for the solar desalination and parameters affecting solar distillation will be presented. Chapter 3 provides a detailed literature survey of the work done in the area of solar distillation. In Chapter 4, the details of the experimental setups used are presented. In Chapter 5, results and discussion related to experiments conducted with and without enhancements are presented. Lastly, in Chapter 6, conclusion and recommendations for future work are provided.

CHAPTER 2

SOLAR DESALINATION

Desalting refers to a water treatment process that removes salts from water. It is also called desalination or desalinization, but it means the same thing. Desalting can be done in a number of ways, but the result is always the same: fresh water is produced from brackish water or seawater.

Throughout history, people have continually tried to treat salty water so that it could be used for drinking and agriculture. Of the entire globe's water, 94 percent is salt water from the oceans and 6 percent is fresh. Of the latter, about 27 percent is in glaciers and 72 percent is underground. While this water is important for transportation and fisheries, it is too salty to sustain human life or farming. Desalting techniques have increased the range of water resources available for use by a community. Until recently, only water with a dissolved solids (salt) content generally below about 1000 milligrams per liter (mg/l) was considered acceptable for a community water supply. This limitation sometimes restricted the size and location of communities around the world and often led to hardship to many that could not afford to live near a ready supply of fresh water. The application of desalting technologies over the past 50 years has changed this in many places. Villages, cities, and industries have now developed or grown in many of the arid

and water-short areas of the world where sea or brackish waters are available and have been treated with desalting techniques.

This change has been very noticeable in parts of the arid Middle East, North Africa, and some of the islands of the Caribbean, where the lack of fresh water severely limited development. Now, modern cities and major industries have developed in some of those areas thanks to the availability of fresh water produced by desalting brackish water and seawater [3].

2.1 Desalination techniques

Desalination can be achieved by using a number of techniques. These may be classified into the following categories:

- Phase change or thermal processes
- Membrane or single-phase processes

In Figure 2.1, the most important technologies in use are listed. In phase change or thermal processes, the distillation of seawater is achieved by utilizing a thermal energy source. The thermal energy may be obtained from a conventional fossil-fuel source, nuclear energy or from a non-conventional solar energy source. In the membrane processes, electricity is used either for driving high-pressure pumps or for ionization of salts contained in seawater [4].

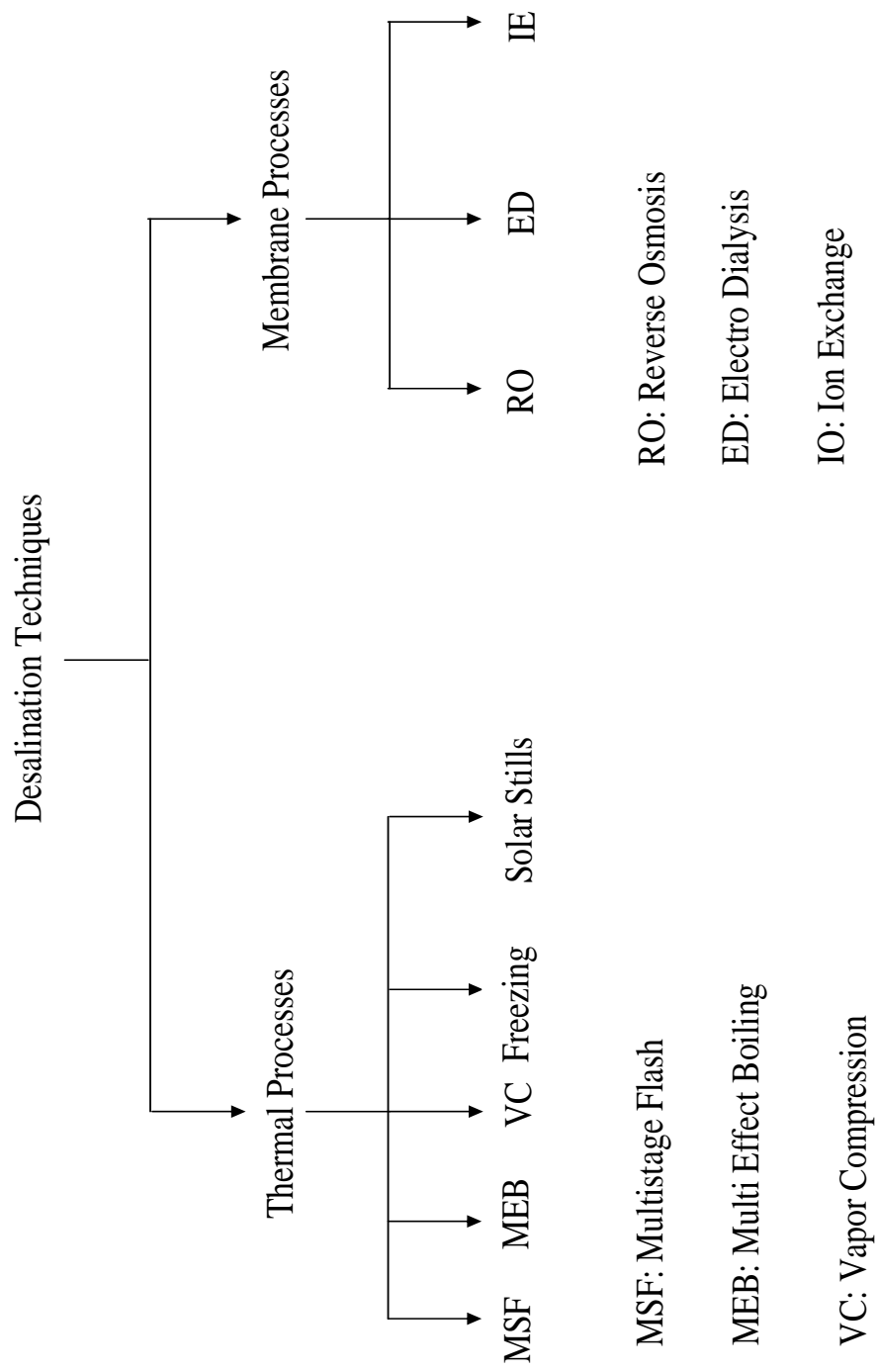


Figure 2.1: Desalination Techniques

2.1.1 Thermal Processes

About half of the world's desalted water is produced with heat to distill fresh water from seawater. The distillation process mimics the natural water cycle in that salt water is heated, producing water vapor that is in turn condensed to form fresh water. In a laboratory or industrial plant, water is heated to the boiling point to produce the maximum amount of water vapor.

To do this economically in a desalination plant, the applied pressure of the water being boiled is adjusted to control the boiling point because of the reduced atmospheric pressure on the water, the temperature required to boil water decreases as one moves from sea level to a higher elevation. Thus, water can be boiled on top of Mt. McKinley, in Alaska [elevation 6,200 meters (20,300 feet)], at a temperature about 16 °C (60.8 °F) lower than it would boil at sea level. This reduction of the boiling point is important in the desalination process for two major reasons: multiple boiling and scale control.

To boil, water needs two important conditions: the proper temperature relative to its ambient pressure and enough energy for vaporization. When water is heated to its boiling point and then the heat is turned off, the water will continue to boil only for a short time because the water needs additional energy (the heat of vaporization) to permit boiling. Once the water stops boiling, boiling can be renewed by either adding more heat or by reducing the ambient pressure above the water. If the ambient pressure were reduced, the water would be at a temperature above its boiling point (because of the reduced pressure) and would flash to produce vapor (steam), the temperature of the water

will fall to the new boiling point. If more vapors can be produced and then condensed into fresh water with the same amount of heat, the process tends to be more efficient.

To significantly reduce the amount of energy needed for vaporization, the distillation desalting process usually uses multiple boiling in successive vessels, each operating at a lower temperature and pressure. Typically 8 tons of distillate can be produced from 1 ton of steam. This process of reducing the ambient pressure to promote additional boiling can continue downward and, if carried to the extreme with the pressure reduced enough, the point at which water would be boiling and freezing at the same time would be reached.

Aside from multiple boiling, the other important factor is scale control. Although most substances dissolve more readily in warmer water, some dissolve more readily in cooler water. Unfortunately, some of these substances, like carbonates and sulfates, are found in seawater. One of the most important is calcium sulfate (CaSO_4), which begins to leave solution when seawater approaches about 115 °C (203 °F). This material forms a hard scale that coats any tubes or surfaces present. Scale creates thermal and mechanical problems and, once formed, is difficult to remove. One way to avoid the formation of this scale is to control the concentration level of seawater and to control the top temperature of the process. Another way is to add special chemicals to the seawater that reduce scale precipitation and permit the top temperature to reach 110°C. These two concepts have made various forms of distillation successful in locations around the world. The process that accounts for the most desalting capacity for seawater is multi-stage flash distillation, commonly referred to as the MSF process [4].

2.1.2 Membrane Processes

In nature, membranes play an important role in the separation of salts, including both the process of dialysis and osmosis, occurs in the body. Membranes are used in two commercially important desalting processes: Electrodialysis (ED) and Reverse Osmosis (RO). Each process uses the ability of the membranes to differentiate and selectively separate salts and water. However, membranes are used differently in each of these processes.

ED is a voltage driven process and uses an electrical potential to move salts selectively through a membrane, leaving fresh water behind as product water. RO is a pressure-driven process, with the pressure used for separation by allowing fresh water to move through a membrane, leaving the salts behind. Scientists have explored both of these concepts since the turn of the century, but their commercialization for desalting water for municipal purposes has occurred in only the last 30 to 40 years [3].

Membrane processes constitute a well-established technology for the desalination of brackish water. Recently, the use of membrane systems has increased substantially and is rapidly expanding its share of the desalination market for brackish water, wastewater reuse, and seawater [4].

2.2 Solar Desalination Systems

A representative example of direct collection systems is the conventional solar still, which uses the greenhouse effect to evaporate salty water. It consists of a basin, in which a constant amount of seawater is enclosed in a v-shaped glass envelope. There are different types of solar stills built in different countries on the world, which in common have a saline water basin with a black bottom, a transparent cover and collecting pipes, which give the condensed water as end product. Sunlight heats the water in the basin. This heated water evaporates and condenses on the underside of the sloping transparent cover and runs down into collecting through along the inside lower edges of the transparent cover, Figure 2.2. Usually the transparent cover is made of glass or plastic such as polyvinyl chloride or polyvinyl fluoride. The basin is covered with a thin black plastic film, like butyl caoutchouc and insulated against the heat losses into the ground [4].

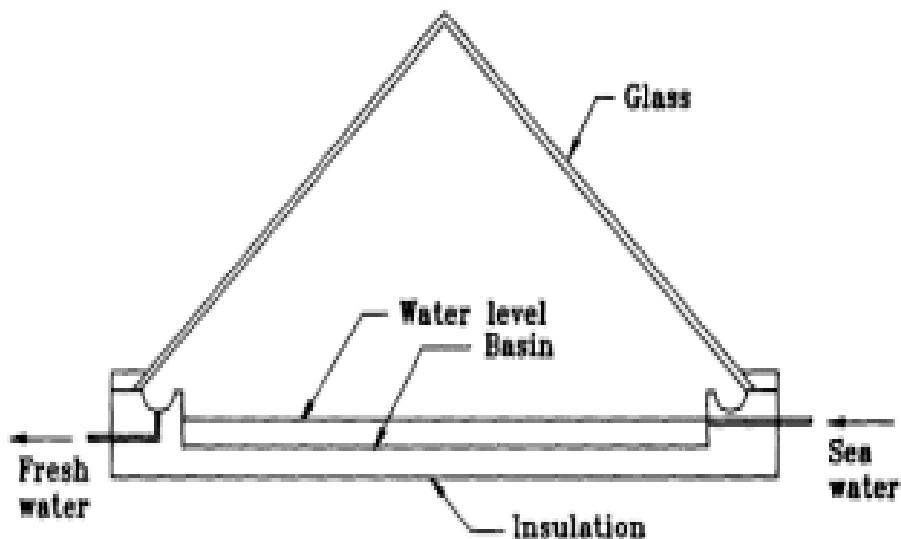


Figure 2.2: Schematic of a solar still

A typical still efficiency, defined as the ratio of the energy utilized in vaporizing the water in the still to the solar energy incident on the glass cover, is 35%(maximum) and daily still production is about 3-4 l/m².

Several attempts have been made to use cheaper materials such as plastics. These are less breakable, lighter in weight for transportation, and easier to set up and mount. Their main disadvantage is there is their shorter life. Many variations of the basic shape have been developed to increase the production rates of solar stills. Some of the most popular are shown in Figure 2.3 [4].

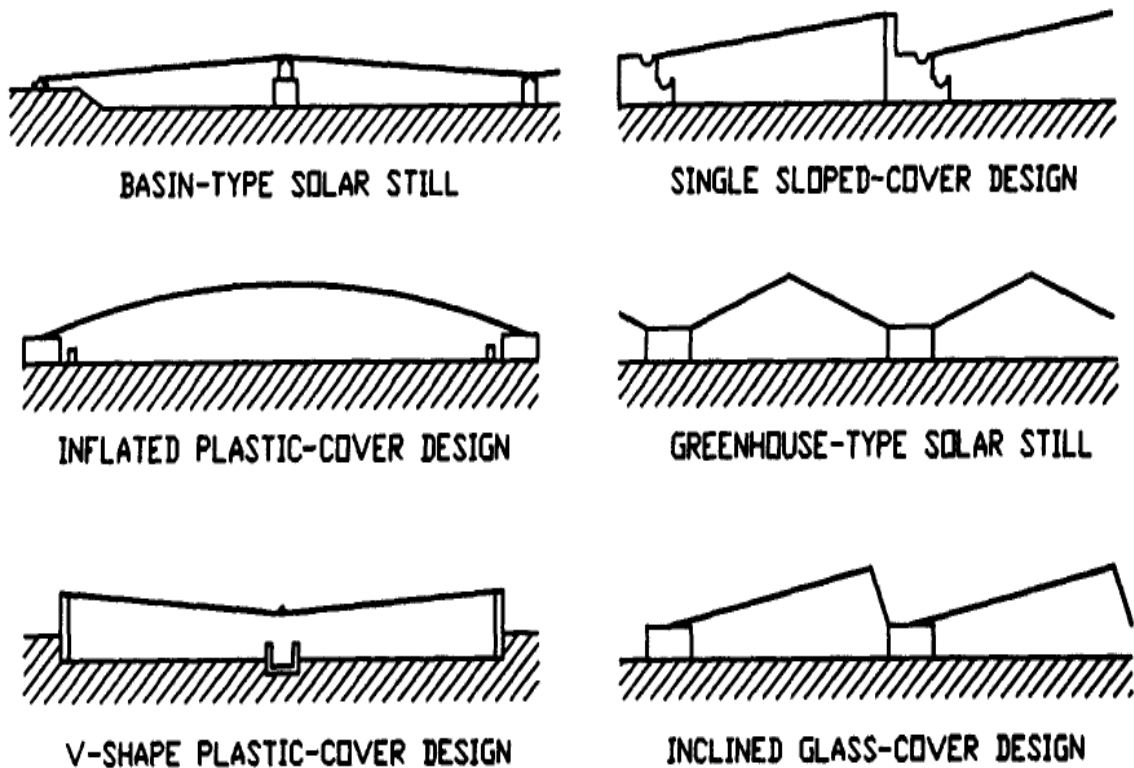


Figure 2.3: Common designs of solar stills

On the islands where underground natural sources are not available and the cost of shipping water to the islands is high, plastic rooftop solar stills are convenient to use, Figure 2.4.

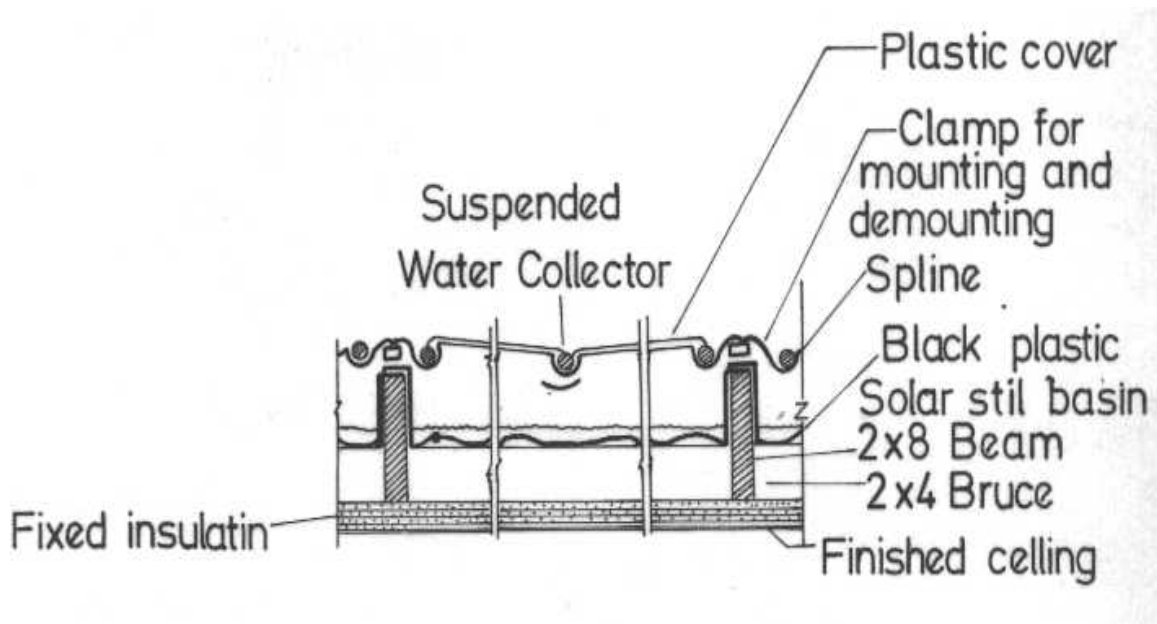


Figure 2.4: Plastic rooftop solar still

This type of a solar still usually consists of a plastic cover, a black plastic solar still basin and a fixed insulation. The water depth should be no more than 2 cm, because of the weight, which brings an additional load to the roof of the building.

Figure 2.5 shows a lightweight collapsible solar still for only few gallons per day of fresh water production. These types of solar stills usually are used for emergency cases on islands, which are used as navy bases.

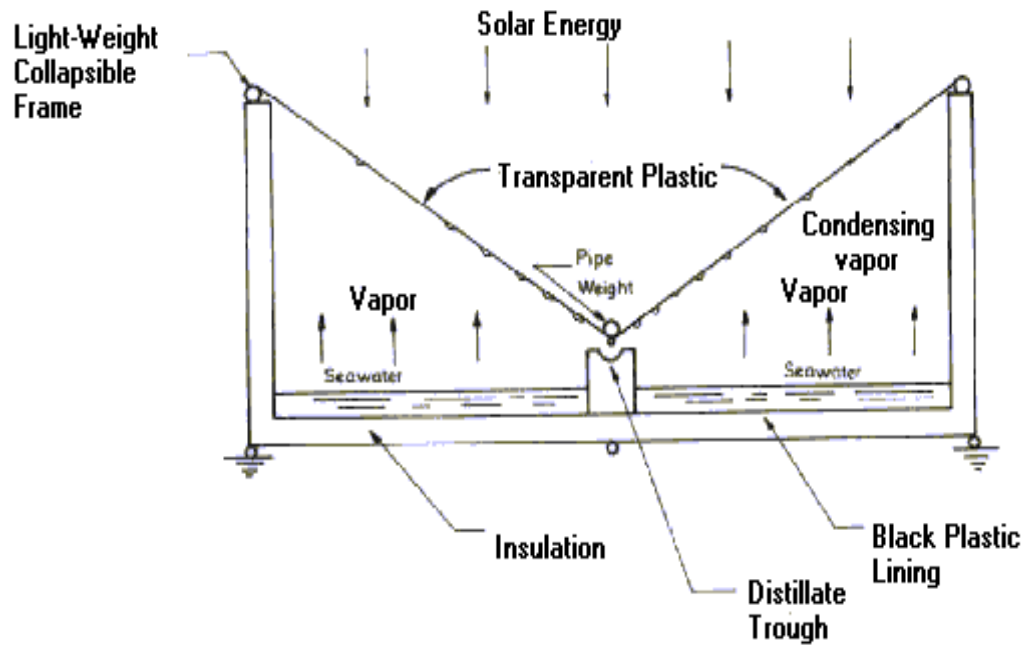


Figure 2.5: Light-weight Collapsible solar still

Figure 2.6 gives the basic concept of a horizontal concentric tube solar still. This solar still utilizes air as working medium. Air carries the water vapor from the annular space between the clear outer and the inner tube through the inside of the inner tube where the water vapor condenses and gives up its heat of condensation directly to the seawater being sprayed on the outer surface of the inner tube. The water vapor will have the preferential tendency to condense on the inside surface of the clear outer tube.

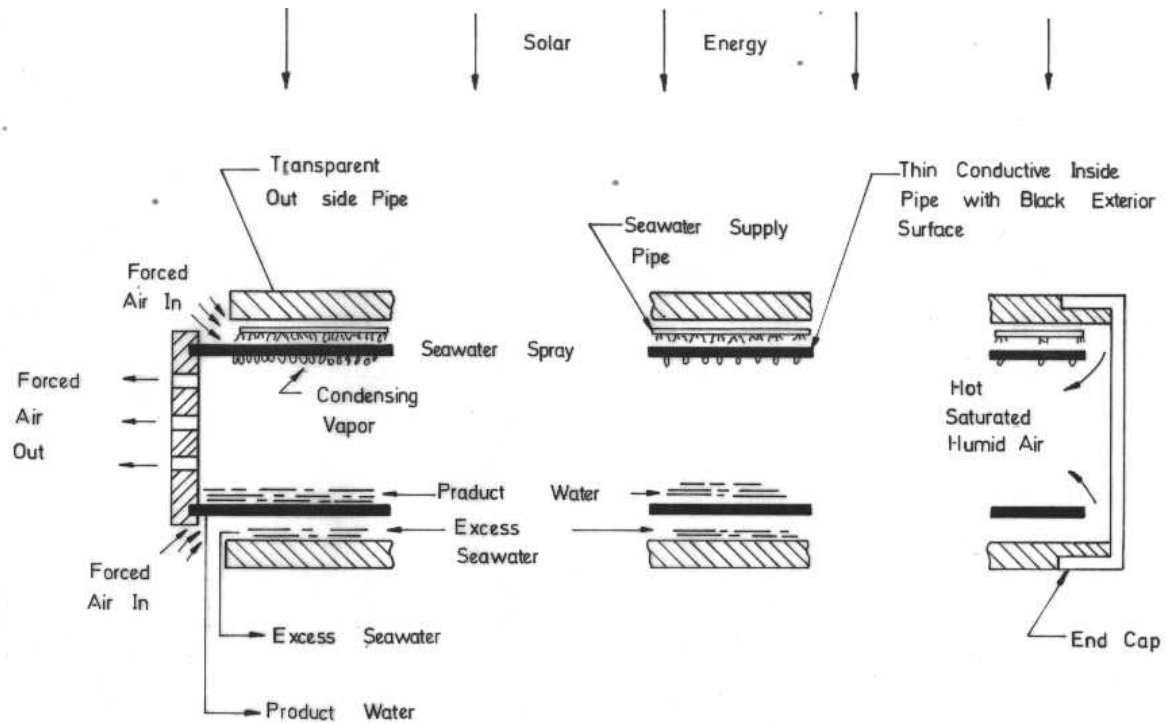


Figure 2.6: Horizontal concentric tube solar still

Figure 2.7 shows high performance solar still. In this type of solar still the heat of condensation of water vapor is received by a working fluid, e.g., water can be used as a working fluid. As shown in Figure 2.7, the working fluid circulates around the solar still. Its temperature is minimum at point 1 and maximum at point 2, from where it flows down on an insulated inclined plane back to the heat exchanger. The heat exchanger is either a double plate or a double pipe type. In the latter case, the outer pipe has perforations on it. The seawater enters the annular space and evaporates on receiving heat from working fluid. The issuing vapor then rises and condenses on a glass plate as it gives up its heat to the working fluid [5].

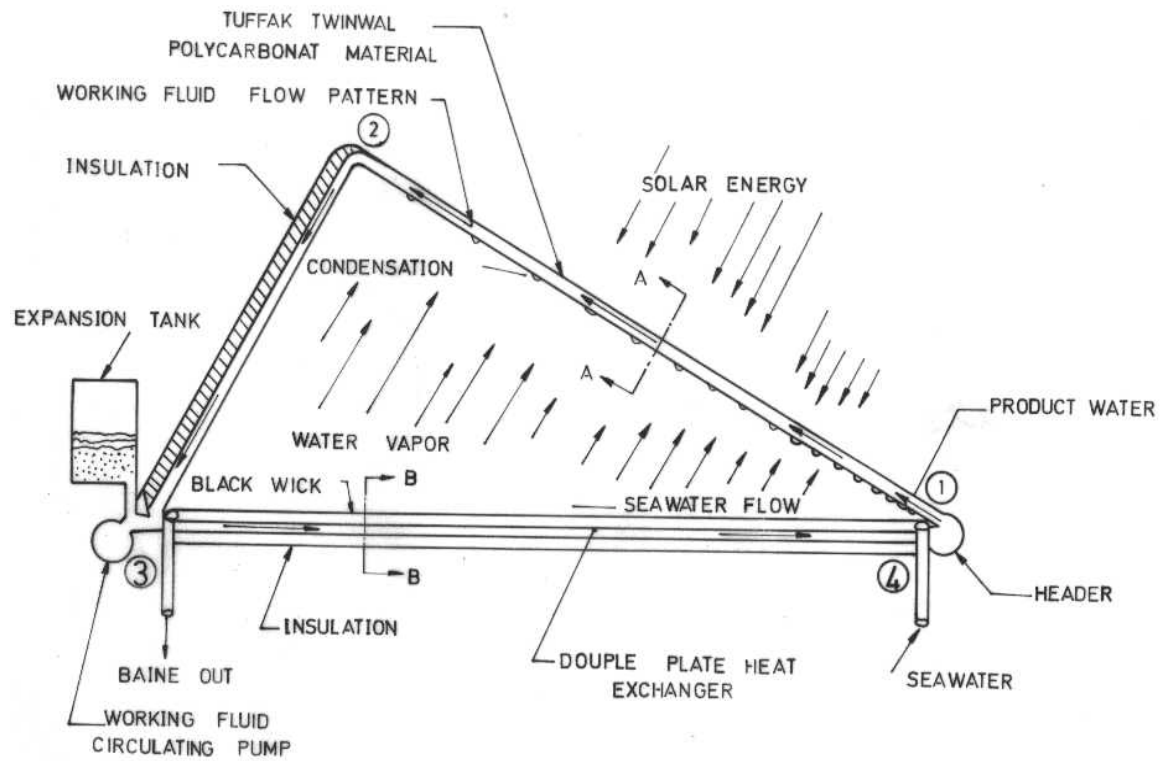


Figure 2.7: High performance solar still

Figure 2.8 shows cylindrical parabolic type solar still. It has a parabolic reflector; the reflector was designed to concentrate the incident solar radiation on the black outside surface of a tray located on the focal line of the reflector [6].

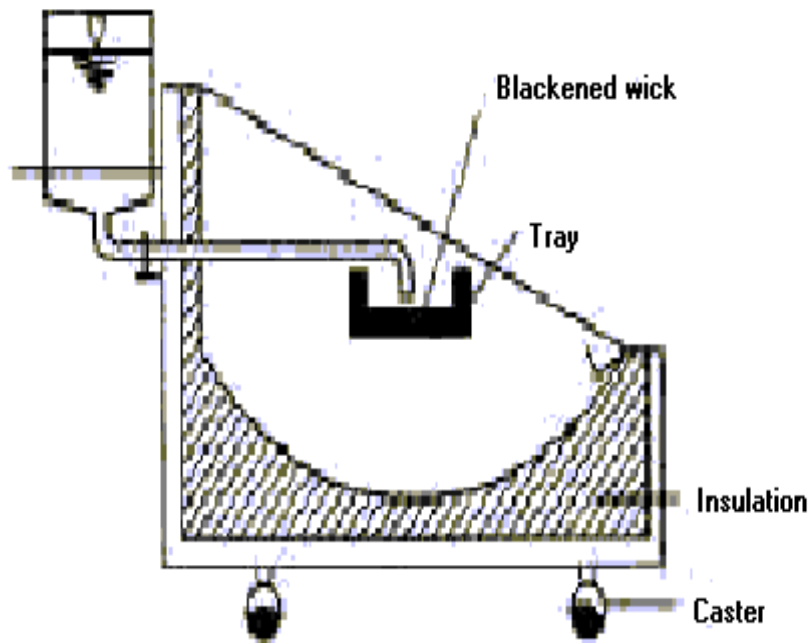


Figure 2.8: Cylindrical Parabolic type

In double basin solar still the transparent glass cover and glass plate transmit solar radiation. The absorbing plate is then heated directly by solar radiation. The saline water feeds are introduced on the upper surfaces of both the absorbing and glass plates where some water evaporates, while the remainder is collected at the bottom and discarded as concentrated brine [7]. (Figure 2.9)

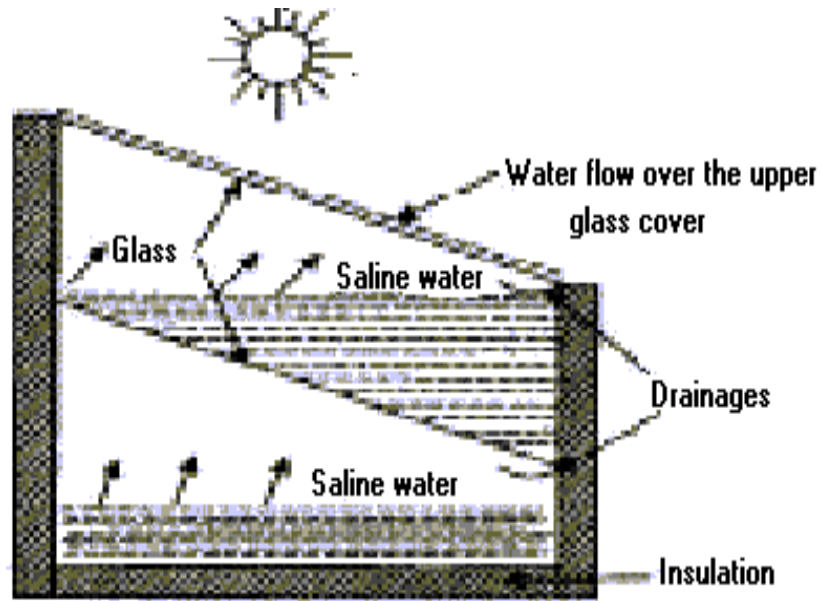


Figure 2.9: Stationary double-basin still with flowing water over upper basin

Another type of solar still that is designed to operate with a very low heat capacity is the tilted-wick solar still. Figure 2.10 shows tilted wick solar still [8].

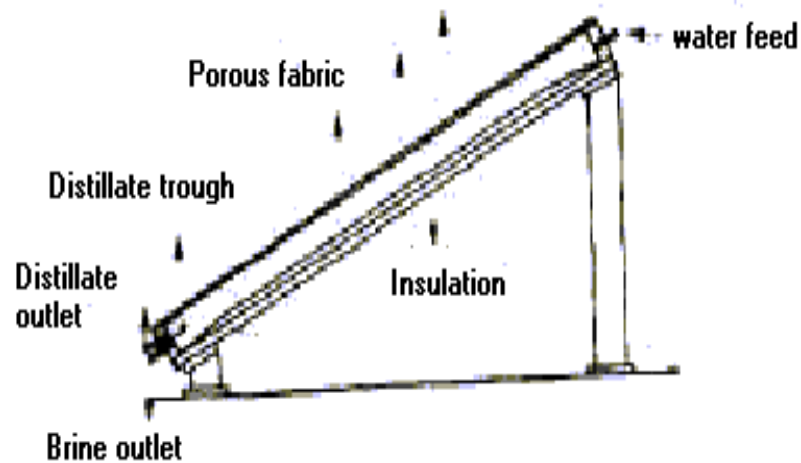


Figure 2.10: Tilted wick solar still

2.3 Parameters Affecting the Output of a Solar Still

The productivity of a still is under the effect of three groups of conditions.

- Ambient conditions
- Operating conditions
- Design conditions

Ambient conditions are ambient temperature, insolation, and wind velocity. Operating conditions are depth of water, the orientation of the still and inlet temperature of water, etc. Design conditions are the selection of the material of the still and cover, slope of the cover, distance between the water and the cover (gap distance) and number of covers used, etc. It is clear that ambient conditions are not under control, and a optimum design must satisfy the requirements of the operating conditions and design conditions [9].

2.3.1 Solar radiation

The effect of solar radiation on the productivity of the still has been investigated by many researchers. The results indicated that the solar radiation is the most affecting parameter on the productivity of still and is more during summer compared to winter. In general, the productivity of the solar still increases as the incident solar radiation increases.

2.3.2 Cover Thickness and Material

The most expensive item of a still is the transparent cover. Plastic and glass are the preferred one for the top cover of which plastic is the least expensive. The common problems encountered by the plastic are:

1. Fragility and short service life
2. Leakage of water vapor and condensate
3. Over-heating and melting in extreme hot climatic conditions
4. Susceptibility to damage by wind and other elements of nature
5. Reduced transmission of solar radiation because the plastic cover surface does not get wetted

Glass with higher solar transmittance for various angle of incidence and long service life is the preferred material. The heat transfer through the cover plate increases with decrease in thickness and increase in thermal conductivity. Experimental results show that a solar still with glass cover plate with 3 mm thickness gives 16.5% more production than the cover with 6mm glass thickness [10].

2.3.3 Direction and Inclination of Cover

The inclination and the direction of the cover depend on latitude of the location [11]. A study by Cooper showed that evaporation rate actually decreases with cover slope variation from 0° to 45° , rises at about 60° and falls again beyond 75° [13]. The cover with inclination angle equal to latitude will receive sun rays throughout the year. Sun rays are close to normal on south facing cover for lower latitude regions and for the remaining part of year the sun rays are close to normal on north facing cover. For places with

latitude higher than 20° , single slope still is preferable. If the double slope still is used, only one side of the cover will receive the sun rays and other side will be on the shadow side for sun rays. For north latitude places the single slope still with south facing cover for south latitude place north facing cover are preferable [16].

For the solar still, cover inclination angle helps in to collect condensate water using collecting tray. If the inclination is less than required, the drops on the inner surface of top cover will fall back into basin. If the inclination angle is so large to present as a grazing surface to the solar rays at noon, when the solar intensity is maximum then it would cut off a very large fraction of the total daily insolation [15].

2.3.4 Wind Velocity

The productivity increases as the cover temperature decreases. The temperature difference between glass and water increases as the cover temperature decreases in turn, increasing the natural circulation of air mass inside still. It increases both convective and evaporative heat transfer between basin water to cover.

The higher the wind velocity, the higher will be convective heat transfer from the cover to the atmosphere. Soliman has studied the effect of wind velocity on output in detail, considering all heat and mass transfer modes. He has concluded that at high water temperature, the increase in the difference between water and cover temperatures by increasing wind speed causes an increase in the rate of evaporation [17].

2.3.5 Water Depth

The depth of water in the basin affects the performance of a still considerably. At low water depths, the thermal capacity will be lower and hence the increase in water temperature will be faster resulting in higher outputs. Water depth becomes important especially in the morning when low energy from the sun is available and it is required to heat the water quickly to producing fresh water. Hence the only solution is to operate the still at lower depths. An increase in the water depth from 1.27 cm to 30 cm reduces the output by 30% [10].

2.3.6 Energy Absorption and Storing Materials

Solar radiation reflected back from the solar still from Table 1.1 is 11%. If the absorption coefficient of water and basin is increased then this amount of loss can be brought down. Addition of dye to water is the cheapest way to improve the absorption capacity of water. The top surface of the water when the dye is added absorbs solar radiation increasing the temperature which in turn increases the evaporation rate. According to Rajvanshi, addition of black naphthylamine dye at 172.5 ppm increased the production rate by 29% [19].

Glass, rubber and gravel were used by Nafey et al., in order to store more amount of heat energy and increase the heat capacity of basin in addition to increasing the basin heat absorption. Experimental results show that black rubber with 10 mm size increases the productivity of deep basin still by 20% and black gravel with 20-30mm size increases the productivity of a shallow basin still by 19% [20].

2.3.7 Evaporation and Condensing Area of the Basin

Different kinds of materials like rubber mat, pebbles, sand, fins and sponges were used by Velmurugan et al., of which, combination of fins and sponges in the basin has the best production rate. Using of fins on the basin increases the exposure area to solar radiation, more thermal energy is absorbed increasing the sensible heat in the saline water which in turn increases the water productivity. When sponges are used along with the fins, the water surface area is increased increasing the productivity. Due to capillary action, water raises to the exposure area of the sponges and thus free water surface increases [22].

The bottom surface of the top cover is the only available area for condensation in a solar still. The condensation rate can be increased by providing additional area for condensation. For places with higher latitudes, when double slope still is used half of the area will be in shadow region. This half area in shadow region can be used as an inbuilt condenser. Condenser cover can be provided with fins on its outer surface to enhance the convection heat transfer to atmosphere [23].

2.3.8 Salt Concentration

The effect of salt concentration on the output of a still has been studied in detail by Baibutayev et al. The experiments have shown that as the salt concentration of the water to be distilled increases right up to the saturation point, the output of the still falls linearly and slowly. However, as the salt concentration of the water to be distilled increases, there is an increase in the corrosion damage to the components of the still [25].

2.3.9 Gap distance

Reducing the gap distance between the evaporating surface and the condensing cover improves the still performance. The effect of the gap distance is much important than the effect of the cover slope. Reducing the gap distance will reduce the height of the walls of the still and hence will reduce the shadowing effect of these sides. Also less time is elapsed by the saturated air to reach the condensing surface and therefore continuous and quicker air movement in the still is established. Reducing the gap distance from 13.0 cm to 8 cm for the same cover slope increases the output by 11.0% [9].

2.3.10 Number of Covers

Number of transparent covers used in a solar still does not increase the output, because it increases the temperature of the inner cover (condensing surface). But it also keeps the still airtight. Due to double glass cover reduction of 25-35 % of the output was noticed. Also uses a double glass cover increases the initial cost of the still [9].

CHAPTER 3

LITERATURE SURVEY

The research in the area of solar distillation started long time ago. The earliest documented work is that of Arab alchemist in 1551 [1]. This chapter presents a detailed literature survey about the work published in the area of solar distillation with a particular interest in the performance enhancement techniques.

The conventional solar still, was first designed and fabricated in 1872 near Las Salinas in Northern Chile by Carlos Wilson, a Swedish engineer. Several wooden bays of size $1.14\text{m} \times 61\text{m}$ were joined together to yield a total surface area of 4700 m^2 , which was covered with glass. The bottom of the bays, exposed to the sun, was blackened with logwood dye and alum. Brackish water was poured into the bays which, upon evaporation, aided by solar energy, condensed over the glass cover and trickled down into the collectors. This device was in operation for about 40 years and yielded more than 4.9 kg of distilled water per square meter of the still surface on a typical summer day [1].

Khan [26] developed a solar still with a vertical mirror at the back. The vertical mirror reflected the solar radiation into the water tray conserving energy even with low sun angles. The floor was a rectangular tray made of copper. Surrounding the tray was a

channel connected with a pipe for the exit of distilled water. The experiments were carried out in Pakistan and the productivity of the still was 4.68 liters/square meter/day.

Elkader [27] presented the experimental results carried out with a solar still with inclined evaporating yute to study the effects of air gap, base slope angle and glass cover slope angle on the performance of the still. In order to investigate the parameters involved in the still, three models were designed, manufactured and tested against some experimental measurements on a still having 1m x 1m-basin area. The models were designed in such a way that they can give different base slope angle and glass slope angle. A comparison between the three models was made for three glass slope angles. The tests were conducted in Egypt and the results showed that the model with the base slope of 15° and glass slope of 35° gave the best results with a daily-desalinated water quantity of 5.6 liter/m² day.

In a conventional solar still the production of fresh water in bright sunny weather and with warm air temperature is about 5-5.5-liter/m² day, according to the depth of the water in the solar still. In some devices it is possible to obtain efficiencies of up to 50% and 60%. The aim of the research was to increase distillation productivity by utilizing the latent heat released by the condensing water steam. For this purpose Cappelletti [28] built a solar still characterized by two basins (B1 and B2) superimposed upon each other. The building materials were a sheet of black Plexiglas for the bottom of the solar still, a sheet of transparent Plexiglas for all boxes, and a sheet of black polystyrene used as insulating material. The solar still was hermetically sealed to reduce the leakage of vapor to the surroundings. The greatest quantity of fresh water obtained by the tested solar still was 1.7-1.8 liter/m² day. This result was achieved in the third week

of July when solar radiation was 27-28 MJ/m² day. These tests were carried out in Italy. The efficiency of the tested solar still was about 0.16.

Minasian et al. [6] evaluated the possibility of increasing the productivity of the conventional basin type solar still by using a cylindrical parabolic reflector while solving the most important maintenance problem usually encountered in the basin type solar still, i.e. salt accumulation. In this study, the productivity of the conventional basin type solar still has been increased by using a stainless steel cylindrical parabolic reflector. The reflector concentrates the incident solar radiation on the black outside surface of a tray located on the focal line of the reflector. Results of the study showed that the productivity of the new proposed still were 25-35 % greater than the productivity of the conventional basin type solar still. These tests were conducted in Iraq.

Kumar et al. [29] presented the annual performance of an active solar still. Analytical expressions for water and glass cover temperatures and yield have been derived in terms of design and climatic parameters. Numerical computations have been carried out for Delhi climatic conditions (latitude: 28° 35' N, Longitude: 77° 12' E). It has been observed that for given parameters, the annual yield is optimum when the collector inclination is 20° and the still glass cover inclination is 15°.

Boukar and Harmim [30] studied the effect of desert climatic conditions on the performance of a simple basin solar still and a similar one coupled to a flat plate solar collector. Tests were conducted at the solar station of Adrar, an Algeria Saharan Site. The performance of the simple still is compared with the coupled one. They were tested for all day productivity under clear sky conditions, with different depth levels of brackish water

for winter and summer period and for a three months round test from January to March 2000. Data were taking during all type of sky conditions. A three months round study showed that the productivity of the simple basin and similar coupled to a flat plate solar collector strongly depends on the solar radiation and ambient temperature. The daily still productivity in summer period varies from 4.01 to 4.34 liter/m²day for simple basin solar still and from 8.02 to 8.07 liter/m²day for the coupled one.

Valsaraj [31] conducted experimental study on solar distillation in a single slope basin still by surface heating the water mass. The study was conducted in a single slope basin solar still after introducing a floating perforated and folded aluminum sheet over the water surface, which concentrates heat energy at the surface layer, prevents the whole water mass from getting heated up by convection (by preventing/reducing transmission of radiation through the water body to the bottom liner) and allows evaporated water particles from the covered segments to escape out into the air gap through the holes on it. The tests were carried out in Trivandrum, India. The distillate yield was found to have improved considerably, especially when the water depth was high. The study also indicated some design features that would further enhance the improvement in output due to the modification made.

Tiwari and Tripath [33][32] studied the effect of different water depths in the basin on the heat and mass transfer coefficients. They found that the convective heat transfer coefficient between water and the condensing cover depends significantly on the water depth in the basin. The experiments were carried out in New Delhi, India.

Badran and Mamlook [33] from Jordan, applied Fuzzy set technique to study the effect of different parameters like wind speed, ambient temperature, solar intensity, sprinklers, coupled with solar collectors, salt concentration and water depth on the productivity of Solar Still. It was concluded that the application of Fuzzy set methodology offers reasonable prediction and assessment for detecting yield in the solar distillation system.

Akash et al. [34] studied the effect of using different absorbing materials in a solar still in Jordan. The daily water productivity increased by 38%, 45% and 60% using black rubber, black ink and black dye respectively. Nafey et al. [20] studied the effect of important parameters on the performance of single slope solar still using four stills under the weather conditions of Egypt. An equation to predict the productivity of a single slope solar still was developed. Aboul-Enein et al. [35] studied the influence of cover slope on productivity and the thermal performance of still both experimentally and theoretically in the weather conditions of Egypt.

El-Sebaili [36] studied the effect of wind speed on the daily productivity of active and passive solar stills. The experiments were carried out in Egypt and the productivity of solar still increased up to a certain typical wind velocity. Abu-Hijleh and Mousa [37] studied the effect of water film cooling of the glass cover on the efficiency of a solar still numerically. An increase in the still efficiency up to 20% can be obtained using the film-cooling parameters properly. Kamal [38] studied the effect of design parameters like cover tilt angle and still orientation on productivity of a single basin solar still both experimentally and numerically in weather conditions of Qatar. They concluded that an optimum transparent cover tilt angle of 12.5° yields the maximum productivity and east-

west orientation of the still gave slightly higher results than the north-south orientation. Garg and Mann [39] studied the effect of climate, design and operational parameters on the performance of single and double slope solar stills. The productivity of solar still increases with the decrease in water depth and the increase of total solar radiation, ambient air temperature and wind speed.

Tamimi [40] studied the effect of internal reflectors (side and back walls) and black dye on productivity of a single slope solar still in the weather conditions of Jordan. They concluded that black dye has a little effect on productivity compared to that of internal reflectors. An increase in efficiency of 20-30% was obtained by using internal reflectors.

Al-Hayek and Badran [41] experimentally studied two different basin type stills in Jordan, the single slope solar still with a reflector on the whole inner surface and the double slope solar still without a reflector. They concluded that the single-slope solar still with reflector is 20% more productive than the double slope solar still without the reflector.

El-Bahi and Inan [42] studied the basin type still with an external reflector in the weather conditions of Turkey. Their still consisted of a basin liner, parallel glass cover and external condenser integrated to the still from behind. The external reflector was used to increase solar radiation incident on the glass cover and to make a shadow for the condenser. They indicated that an external reflector can maintain higher reflectivity than an internal one since there is no condensation on the external surface causing a decrease in reflectivity.

El-Swify and Metias [43] presented a useful geometrical method to calculate the solar radiation reflected by the inner surfaces and then absorbed on the basin liner. They theoretically predicted the increase in solar radiation absorbed on the basin liner caused by the internal reflectors in detail.

Tanaka and Nakatake [44] studied the effect of internal and external reflectors on productivity of basin type still theoretically. They proposed a geometrical method to calculate the solar radiation reflected by the internal and external reflectors and then absorbed on the basin liner. They also performed numerical analysis of heat and mass transfer in the still, and found that the internal and external reflectors can remarkably increase the distillate productivity throughout the year except for the summer season. They obtained an average of 48% increase for the entire year in the daily amounts of distillate.

Khalifa and Hussein [45] experimentally investigated the effect of inclination of external reflector and the internal reflector on the productivity of a single slope solar still for different cover angles of 20° , 30° and 40° . These tests were conducted in Iraq. They found that the daily productivity is greater for a still with a larger cover angle at any reflector angle. The daily productivity of the still with no reflectors would remain almost the same at any glass cover angle. The benefit of the vertical external reflector in winter is decreased as the cover angle exceeds 40° . The most productive solar still in winter is a still that has a cover angle of 20° and an internal and external reflector inclined at 20° ; its productivity will be around 2.45 times that of simple still with no reflectors.

The present study is a partial implementation of two patents [49] and [50] in the field of Solar distillation.

CHAPTER 4

EXPERIMENTAL STUDY OF SOLAR STILL

4.1 Experimental Setup

Four Single slope single basin solar stills were fabricated and tested in King Fahd University of Petroleum and Minerals Campus area (Dhahran, 26°16'N Latitude and 50°10'E Longitude). The basin is made of galvanized iron sheet with a thickness of 3mm and dimensions of 0.5m × 1m × 0.06m as shown in Figure 4.1. The basin surfaces are painted with black paint to absorb the maximum amount of solar radiation incident on them. A scale is fixed along with inside wall for measuring water levels. A hole of diameter 2cm is provided in the basin surface to collect the distilled water. A collecting trough made by glass is used in the still to collect the distillate condensing on the inner surfaces of the glass covers and to pass the condensate through the hole into a collecting flask. The schematic view of the basin is shown in Figure 4.2.



Figure 4.1: Basin with a collecting trough made of glass

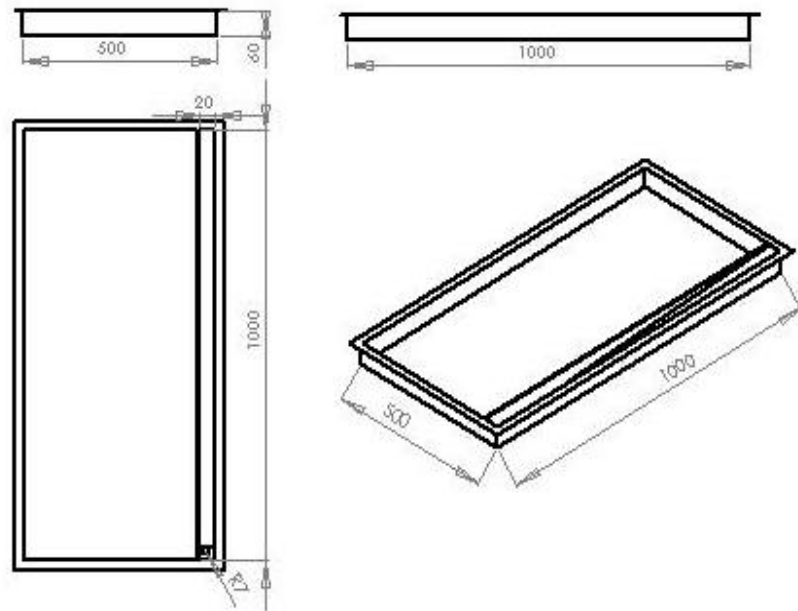


Figure 4.2: Schematic view of the basin

The condenser surface of the still is made of glass with 6mm thickness. There are certain specifications needed for the used glass cover in the still, and they are (a) Minimum amount of absorbed heat, (b) Minimum amount of reflection for solar radiation energy, (c) Maximum transmittance for solar radiation energy, and (d) high thermal resistance for heat loss from the basin to the ambient. Glass cover has been framed with aluminum strips and sealed with silicon rubber, which plays an important role to promote efficient operation as it can accommodate the expansion and contraction between dissimilar materials. Four condenser surfaces are made with different cover slope angles 25° , 30° , 35° and 40° . The schematic views of the condenser surfaces are shown in Figure 4.4, Figure 4.5, Figure 4.6 and Figure 4.7 and all the dimensions are in mm.



Figure 4.3: Condenser surface

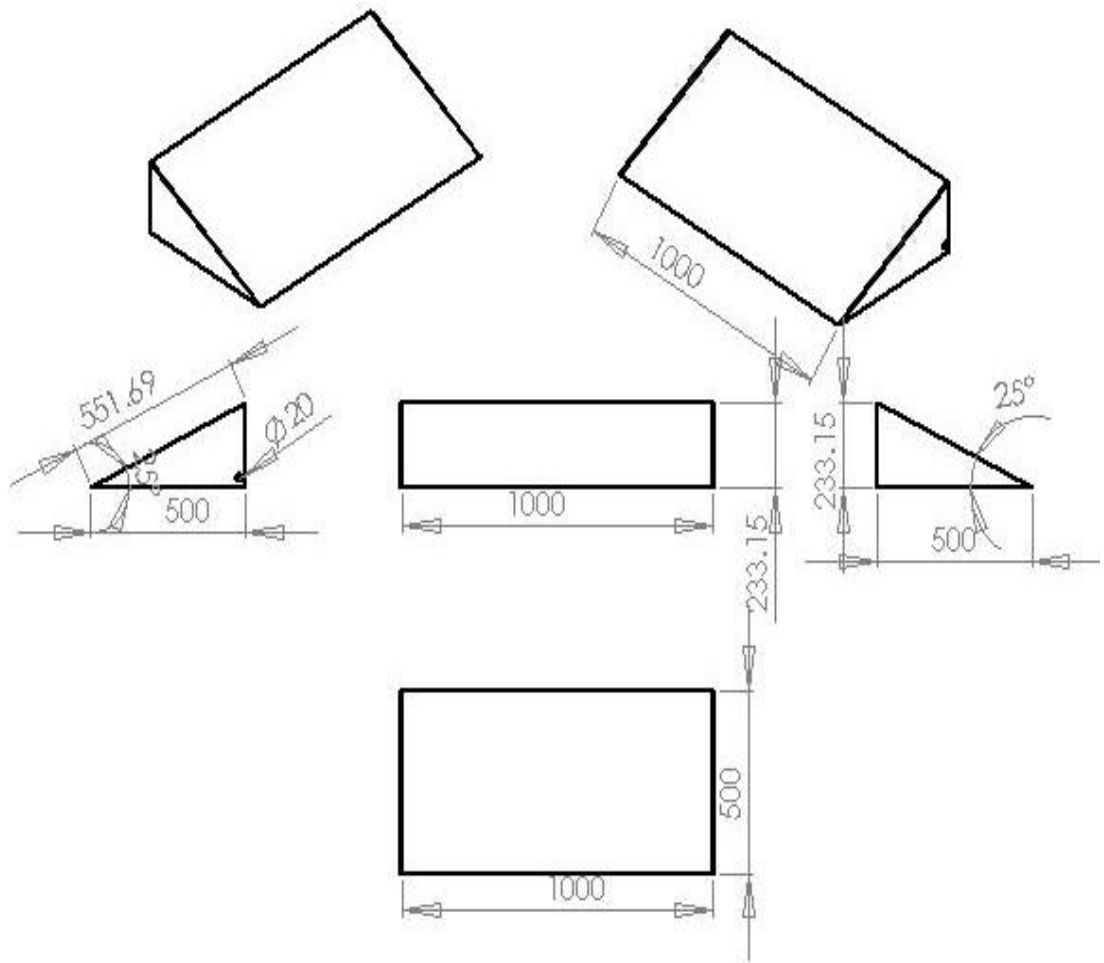


Figure 4.4: Schematic view of Condenser with 25° cover slope angle

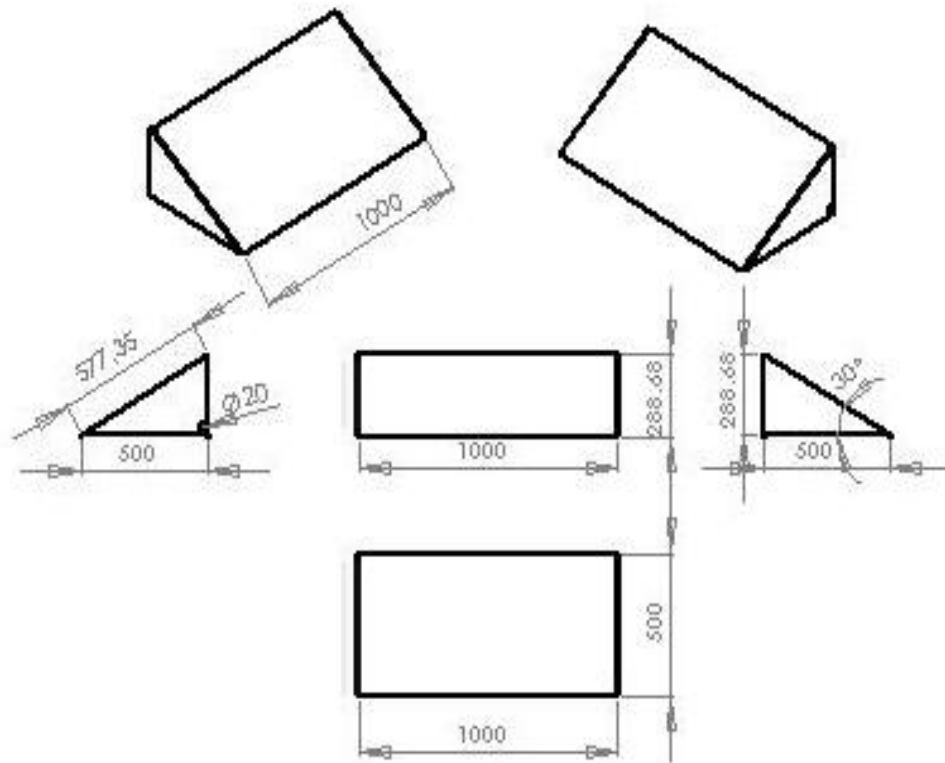


Figure 4.5: Schematic view of Condenser with 30° cover slope angle

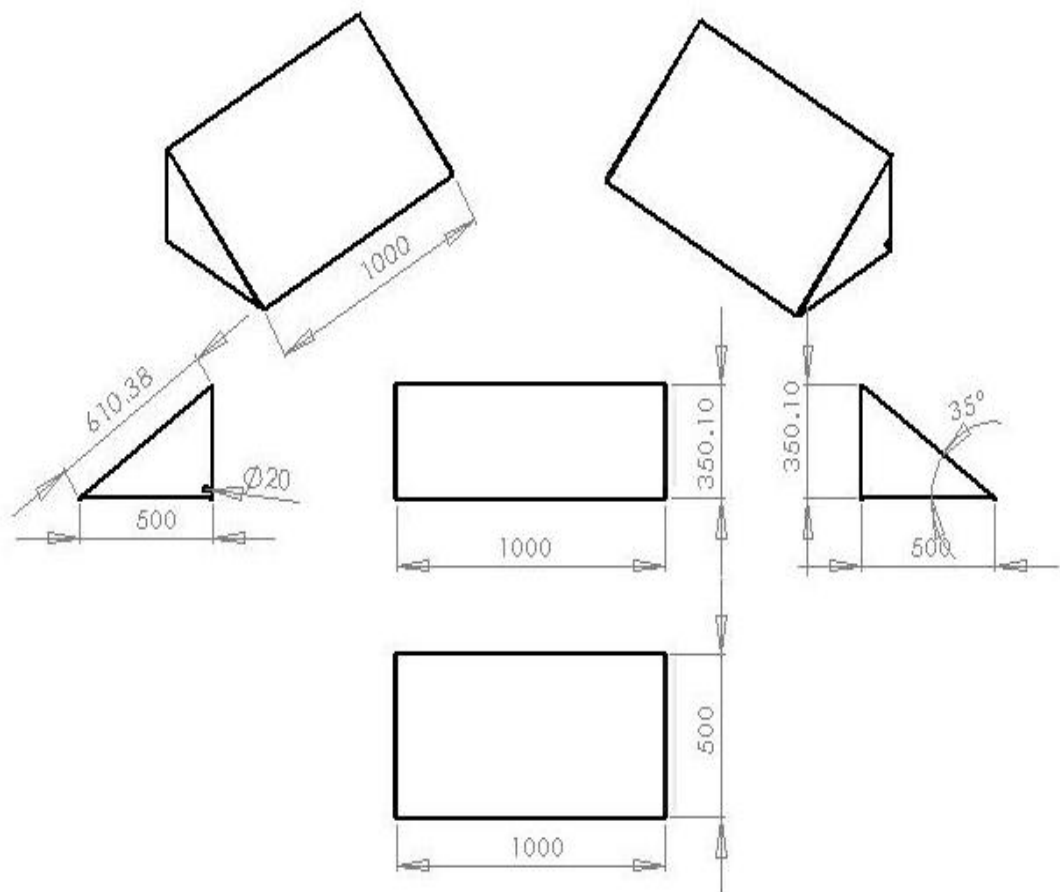


Figure 4.6: Schematic view of Condenser with 35° cover slope angle

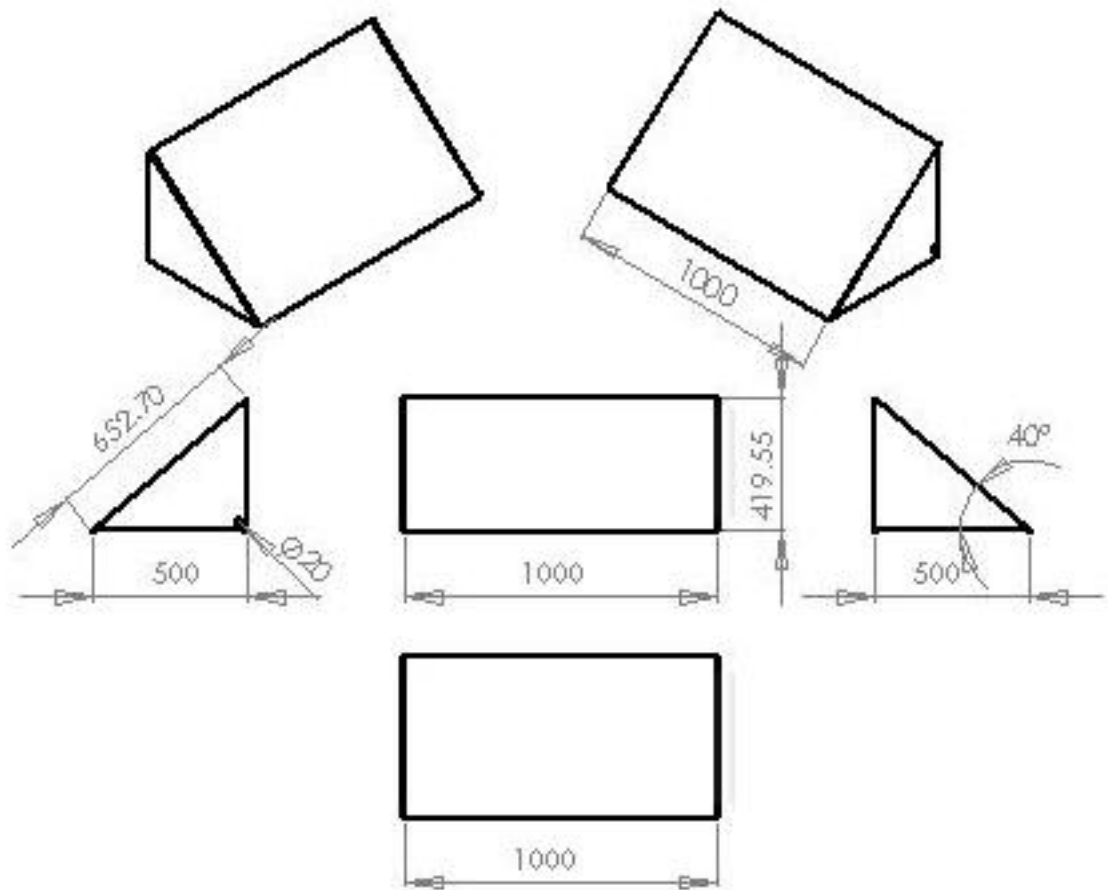


Figure 4.7: Schematic view of Condenser with 40° cover slope angle

The experiments were carried out during the summer season. The stills were placed at a South-North orientation with the glass surface facing south. The experiments were carried out from sunrise to sunset. Hourly recordings for the distilled water, the temperatures of inner and outer glass cover and the water in the basin were made. The ambient temperature, pressure, wind speed and direction were also recorded for every hour.



Figure 4.8: Single slope solar stills with cover slope angles 25° , 30° , 35° and 40°

This study had been performed in two main parts. One of them was carried out without external reflectors and the second was carried out with four external reflectors as shown in Figure 4.9 on four sides of the still. The size of reflectors is same as that of the basin.



Figure 4.9: Single slope solar still with external reflectors and cover slope angle 35°

CHAPTER 5

RESULTS AND DISCUSSION

The experiments were performed in two parts. In the first part, effects of cover slope angle and water depth were studied and the best cover slope angle and water depth were optimized. In the second part, four external reflectors were used from four sides of the still and their effect on productivity was studied.

The experiments were carried out from sunrise to sunset. The ambient temperature, pressure, wind speed and direction were recorded for every hour and are shown in Table 5.1, Table 5.6 and Table 5.11. Hourly recordings of stills with cover slope angles 25°, 30°, 35° and 40° for the distilled water, the temperatures of inner and outer glass cover and the water in the basin were also tabulated.

Time	Temperature	Humidity	Sea Level Pressure	Wind Direction	Wind Speed
6:00 AM	33° c	79%	1000 hPa	SE	7.4 km/h / 2.1 m/s
7:00 AM	37° c	39%	1000 hPa	SE	18.5 km/h / 5.1 m/s
8:00 AM	39° c	37%	1001 hPa	East	22.2 km/h / 6.2 m/s
9:00 AM	40° c	21%	1001 hPa	SE	22.2 km/h / 6.2 m/s
10:00 AM	41°C	38%	1000 hPa	SE	33.3 km/h / 9.3 m/s
11:00 AM	42°C	32%	999 hPa	ESE	29.6 km/h / 8.2 m/s
12:00 AM	44°C	15%	999 hPa	SSE	29.6 km/h / 8.2 m/s
1:00 PM	45°C	17%	998 hPa	SSE	29.6 km/h / 8.2 m/s
2:00 PM	45°C	15%	998 hPa	SE	25.9 km/h / 7.2 m/s
3:00 PM	44°C	14%	998 hPa	SE	18.5 km/h / 5.1 m/s
4:00 PM	43.0 °C	15%	997 hPa	SSE	14.8 km/h / 4.1 m/s
5:00 PM	42.0 °C	16%	997 hPa	SSE	11.1 km/h / 3.1 m/s
6:00 PM	40.0 °C	17%	998 hPa	East	9.3 km/h / 2.6 m/s

Table 5.1: Hourly climate data

Time	Distilled water in ml	Temperature in °C		
		Inner Glass Cover	Outer Glass Cover	Water in the basin
6:00 AM	0	31	31	31
7:00 AM	25	35.6	35.5	36
8:00 AM	45	38.5	37.5	39
9:00 AM	100	42	38.8	44
10:00 AM	180	45	45	50
11:00 AM	240	52	50	55
12:00 AM	340	59	55	64
1:00 PM	347	60	59	65
2:00 PM	300	60	58	64.5
3:00 PM	280	55	54	59
4:00 PM	200	54	48	57
5:00 PM	130	47	46	51
Total Output	2.18 Liters			

Table 5.2: Experimental observations for single slope solar still with 25° cover slope angle & 1cm water depth

Time	Distilled water in ml	Temperature in °C		
		Inner Glass Cover	Outer Glass Cover	Water in the basin
6:00 AM	0	30	30	30
7:00 AM	20	35.2	35	35.5
8:00 AM	45	38	37.6	40
9:00 AM	105	42	41	44.5
10:00 AM	190	46	45.5	50.6
11:00 AM	260	52.5	52	56
12:00 AM	350	59.2	58.2	65
1:00 PM	360	63.4	60	66
2:00 PM	310	63	60	65
3:00 PM	280	56.5	56	60
4:00 PM	200	54.5	51.5	57.5
5:00 PM	130	48	48	52
Total Output	2.25 Liters			

Table 5.3: Experimental observations for single slope solar still with 30° cover slope angle & 1cm water depth

Time	Distilled water in ml	Temperature in °C		
		Inner Glass Cover	Outer Glass Cover	Water in the basin
6:00 AM	0	30	31	30
7:00 AM	25	35	31.8	35
8:00 AM	50	38	34.4	39
9:00 AM	130	41	37.5	45
10:00 AM	225	46.3	41.2	51.2
11:00 AM	280	53	45.2	58.2
12:00 AM	360	59.8	53	64.5
1:00 PM	370	60.5	57.3	65.5
2:00 PM	320	62	57.8	65
3:00 PM	290	57.6	55.6	60
4:00 PM	210	54	52.4	58
5:00 PM	140	50.3	49.5	54
Total Output	2.42 Liters			

Table 5.4: Experimental observations for single slope solar still with 35° cover slope angle & 1cm water depth

Time	Distilled water in ml	Temperature in °C		
		Inner Glass Cover	Outer Glass Cover	Water in the basin
6:00 AM	0	30	30	30
7:00 AM	20	34.5	34.6	34.5
8:00 AM	40	37.5	37	38.5
9:00 AM	120	42.5	42	44.5
10:00 AM	210	46.5	46.1	51
11:00 AM	275	53.7	52	56.4
12:00 AM	350	59.5	59	65.1
1:00 PM	360	63.5	60.2	65.5
2:00 PM	315	63.5	61	65.5
3:00 PM	280	57.9	57	60.7
4:00 PM	210	54.8	52	57.7
5:00 PM	140	50	49	53
Total Output	2.32 Liters			

Table 5.5: Experimental observations for single slope solar still with 40° cover slope angle & 1cm water depth

Time	Temperature	Humidity	Sea Level Pressure	Wind Direction	Wind Speed
6:00 AM	31 ^o c	29%	1000 hPa	NW	13 km/h / 3.6 m/s
7:00 AM	34 ^o c	30%	1000 hPa	WNW	11.1 km/h / 3.1 m/s
8:00 AM	39 ^o c	29%	1000 hPa	NNW	24.1 km/h / 6.7 m/s
9:00 AM	40 ^o c	27%	1001 hPa	North	31.5 km/h / 8.7 m/s
10:00 AM	42°C	22%	1001 hPa	North	29.6 km/h / 8.2 m/s
11:00 AM	44°C	13%	1001 hPa	North	35.2 km/h / 9.8 m/s
12:00 AM	45°C	11%	1000 hPa	NNE	33.3 km/h / 9.3 m/s
1:00 PM	45°C	10%	1000 hPa	North	31.5 km/h / 8.7 m/s
2:00 PM	44°C	13%	1000 hPa	NNE	31.5 km/h / 8.7 m/s
3:00 PM	43°C	18%	1000 hPa	North	29.6 km/h / 8.2 m/s
4:00 PM	42.0 °C	15%	999 hPa	North	29.6 km/h / 8.2 m/s
5:00 PM	41.0 °C	15%	999 hPa	North	29.6 km/h / 8.2 m/s
6:00 PM	38.0 °C	21%	1000 hPa	North	22.2 km/h / 6.2 m/s

Table 5.6: Hourly climate data

Time	Distilled water in ml	Temperature °C		
		Inner Glass Cover	Outer Glass Cover	Water in the basin
6:00 AM	0	29	30	29
7:00 AM	20	33.8	32	34
8:00 AM	40	38	33	39
9:00 AM	95	39.2	36.4	41
10:00 AM	160	43	38	48
11:00 AM	220	48.3	43	54
12:00 AM	300	54	50	58
1:00 PM	335	57.5	54	63
2:00 PM	290	59	57	62
3:00 PM	270	55.3	55	59.5
4:00 PM	200	54.5	51	57.3
5:00 PM	130	50	48	52
Total Output	2.06 Liters			

Table 5.7: Experimental observations for single slope solar still with 25° cover slope angle & 2 cm water depth

Time	Distilled water in ml	Temperature in °C		
		Inner Glass Cover	Outer Glass Cover	Water in the basin
6:00 AM	0	28	29	28
7:00 AM	20	33.5	32	33.5
8:00 AM	40	39	33.6	39.4
9:00 AM	100	41	37	42
10:00 AM	170	44	39	49
11:00 AM	230	51	44	57
12:00 AM	340	58	51	63
1:00 PM	347	59	55.1	66
2:00 PM	290	60	57.5	63
3:00 PM	280	55	55.2	60.8
4:00 PM	190	55	52.2	58.5
5:00 PM	130	52	50	54
Total Output				

Table 5.8: Experimental observations for single slope solar still with 30° cover slope angle & 2 cm water depth

Time	Distilled water in ml	Temperature °C		
		Inner Glass Cover	Outer Glass Cover	Water in the basin
6:00 AM	0	29	30	29
7:00 AM	20	32.5	31.5	33
8:00 AM	45	36.2	33.4	38
9:00 AM	110	39.2	37.6	43
10:00 AM	195	45	40	50.1
11:00 AM	260	51.3	45	58
12:00 AM	350	56	52.5	61.2
1:00 PM	360	57.5	56.4	64
2:00 PM	310	60	58.4	64.1
3:00 PM	280	57.5	56	62
4:00 PM	210	56	52.8	60
5:00 PM	140	52.2	51	55.8
Total Output	2.28 Liters			

Table 5.9: Experimental observations for single slope solar still with 35° cover slope angle & 2 cm water depth

Time	Distilled water in ml	Temperature in °C		
		Inner Glass Cover	Outer Glass Cover	Water in the basin
6:00 AM	0	29	30	29
7:00 AM	20	32	31	33
8:00 AM	35	35.8	33	37
9:00 AM	100	38.4	37	42.2
10:00 AM	180	44	39.7	49.5
11:00 AM	245	50	44.2	57
12:00 AM	340	56	52	60.4
1:00 PM	355	57	55	63.7
2:00 PM	305	60	58	63
3:00 PM	280	57.5	55.9	61.3
4:00 PM	210	56	52.7	59
5:00 PM	140	52.2	51	55
Total Output	2.21 liters			

Table 5.10: Experimental observations for single slope solar still with 40° cover slope angle & 2 cm water depth

Time	Temperature	Humidity	Sea Level Pressure	Wind Direction	Wind Speed
6:00 AM	30 ^o c	58%	1000 hPa	WNW	7.4 km/h / 2.1 m/s
7:00 AM	34 ^o c	41%	1000 hPa	NW	7.4 km/h / 2.1 m/s
8:00 AM	37 ^o c	30%	1000 hPa	WNW	11.1 km/h / 3.1 m/s
9:00 AM	41 ^o c	20%	1000 hPa	West	9.3 km/h / 2.6 m/s
10:00 AM	42°C	16%	1000 hPa	NW	9.3 km/h / 2.6 m/s
11:00 AM	43°C	13%	1000 hPa	NNW	7.4 km/h / 2.1 m/s
12:00 AM	45°C	19%	999 hPa	Variable	3.7 km/h / 1 m/s
1:00 PM	45°C	21%	999 hPa	East	16.7 km/h / 4.6 m/s
2:00 PM	44°C	15%	999 hPa	NE	18.5 km/h / 5.1 m/s
3:00 PM	43°C	15%	998 hPa	NE	18.5 km/h / 5.1 m/s
4:00 PM	41°C	17%	998 hPa	ENE	13.0 km/h / 3.6 m/s
5:00 PM	40 °C	16%	998 hPa	NE	16.7 km/h / 4.6 m/s
6:00 PM	38 °C	16%	998 hPa	NE	13.0 km/h / 3.6 m/s

Table 5.11: Hourly climate data

Time	Distilled water in ml	Temperature in °C		
		Inner Glass Cover	Outer Glass Cover	Water in the basin
6:00 AM	0	28	29	28
7:00 AM	20	32	31.5	33
8:00 AM	35	37	33	38
9:00 AM	90	38.8	33.1	40
10:00 AM	145	42	34.3	47.2
11:00 AM	200	47.1	42	53
12:00 AM	270	53	49	57
1:00 PM	310	57.5	53	62
2:00 PM	270	58	56	61
3:00 PM	250	55.7	55.5	60
4:00 PM	200	52.5	52	58
5:00 PM	130	50.2	49	53
Total Output	1.92 Liters			

Table 5.12: Experimental observations for single slope solar still with 25° cover slope angle & 3 cm water depth

Time	Distilled water in ml	Temperature in °C		
		Inner Glass Cover	Outer Glass Cover	Water in the basin
6:00 AM	0	27.5	28.5	27.4
7:00 AM	20	31.4	31	32.5
8:00 AM	35	36.5	32.7	39
9:00 AM	90	40	34.7	41.5
10:00 AM	155	43	36	49
11:00 AM	210	50	44	56
12:00 AM	290	55	51	60
1:00 PM	320	60	55	65
2:00 PM	270	59	57	62.5
3:00 PM	250	56.3	56	60
4:00 PM	200	53	52	58
5:00 PM	140	51	50	53.5
Total Output	1.98 Liters			

Table 5.13: Experimental observations for single slope solar still with 30° cover slope angle & 3 cm water depth

Time	Distilled water in ml	Temperature °C		
		Inner Glass Cover	Outer Glass Cover	Water in the basin
6:00 AM	0	27.5	28	27
7:00 AM	20	31.2	30.5	32
8:00 AM	40	36	32.5	39.8
9:00 AM	100	40.4	35.6	42.4
10:00 AM	170	44	37.5	50.3
11:00 AM	240	52	45	57.3
12:00 AM	325	57.5	52	61.1
1:00 PM	315	61.5	56	66.1
2:00 PM	285	60	58	63.2
3:00 PM	270	57	56.5	61
4:00 PM	210	54.4	53.3	59
5:00 PM	145	52.4	50.7	55
Total Output	2.13 Liters			

Table 5.14: Experimental observations for single slope solar still with 35° cover slope angle & 3 cm water depth

Time	Distilled water	Temperature °C		
		Inner Glass Cover	Outer Glass Cover	Water in the basin
6:00 AM	0	27.5	29.6	27
7:00 AM	20	31.2	30.6	31.4
8:00 AM	30	35.7	33	38.5
9:00 AM	90	40	35.4	41.8
10:00 AM	160	43.5	37.1	49.6
11:00 AM	220	51	45	56.4
12:00 AM	300	56.8	52	60.5
1:00 PM	330	60.8	56.2	65.5
2:00 PM	280	59.4	56	62.9
3:00 PM	260	56.8	55	60.4
4:00 PM	210	54	53.3	58.3
5:00 PM	150	52	50.1	54.1
Total Output	2.05 Liters			

Table 5.15: Experimental observations for single slope solar still with 40° cover slope angle & 3 cm water depth

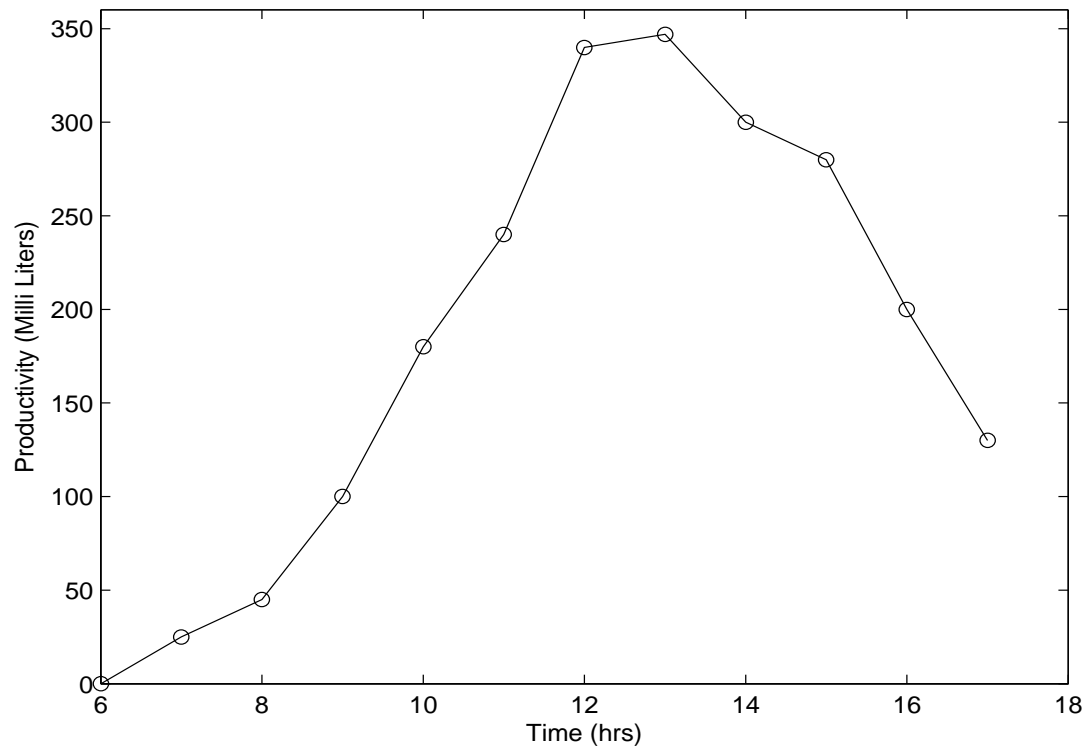


Figure 5.1: Hourly productivity of still with cover slope angle 25° in summer

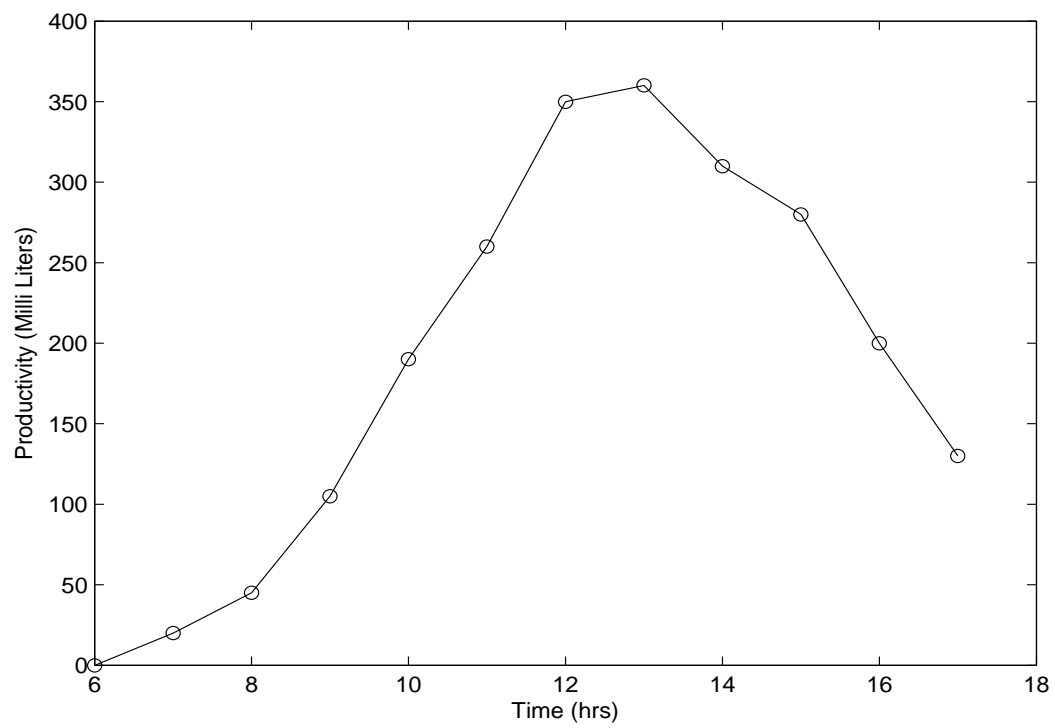


Figure 5.2: Hourly productivity of still with cover slope angle 30° in summer

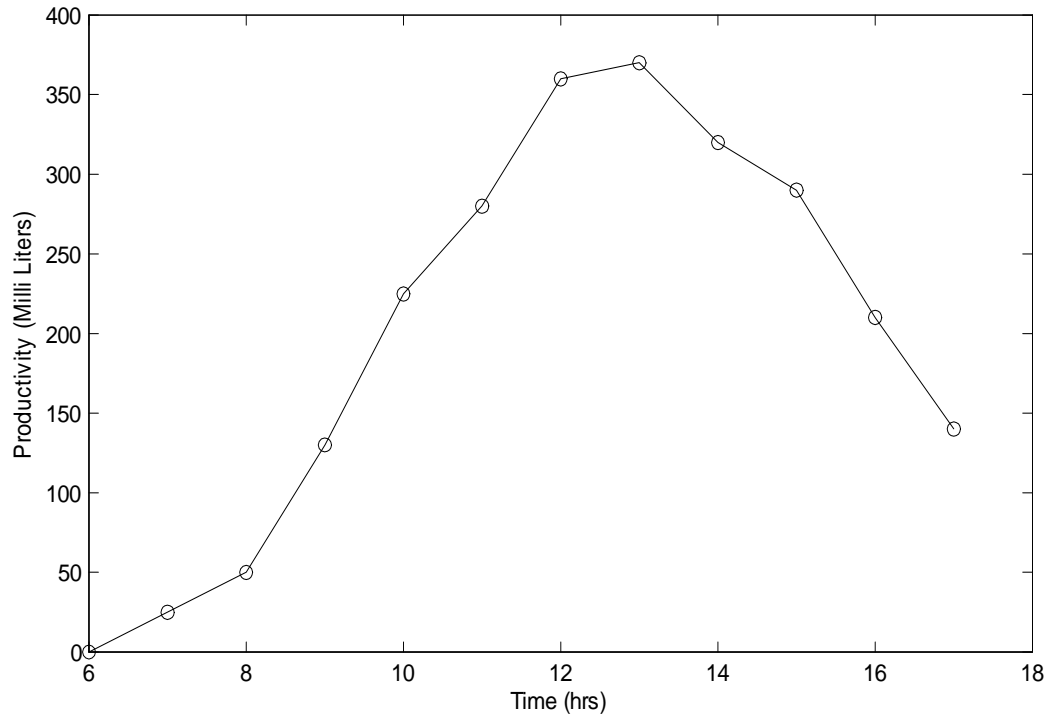


Figure 5.3: Hourly productivity of still with cover slope angle 35° in summer

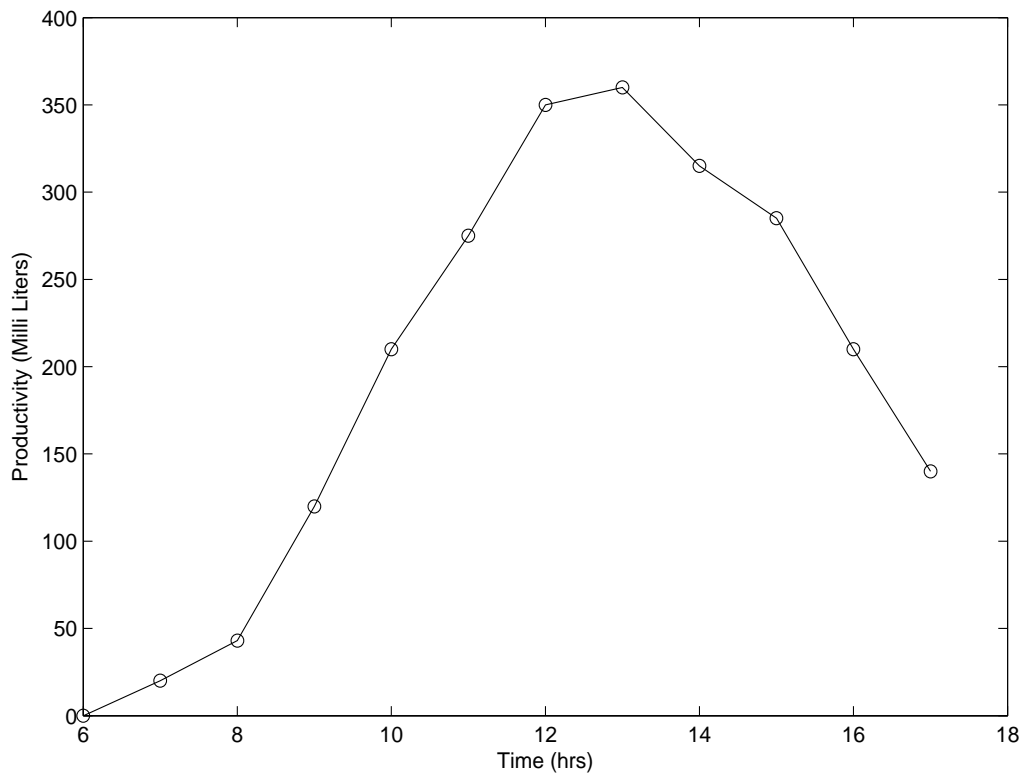


Figure 5.4: Hourly productivity of still with cover slope angle 40° in summer

The performance of the single slope solar stills with cover slope angles 25° , 30° , 35° and 40° and 1 cm water depth on a typical day in June are shown in Figure 5.1, Figure 5.2, Figure 5.3 and Figure 5.4 respectively.

Figure 5.5 to Figure 5.8 show the experimental results for a typical day in June. It can be seen that an increase in water temperature occurs until it reaches the maximum in the afternoon because the absorbed solar radiation exceed the losses to the atmosphere. From about 2 pm, water temperature decreases due to the losses from the solar still which becomes larger than the absorbed solar radiation. As the glass temperature is smaller than the water temperature, it causes condensation of vapor on the glass. In the early hours of the morning the difference in glass temperature and the water temperature is smaller causing smaller productivity due to small energy absorbed by the water at these times.

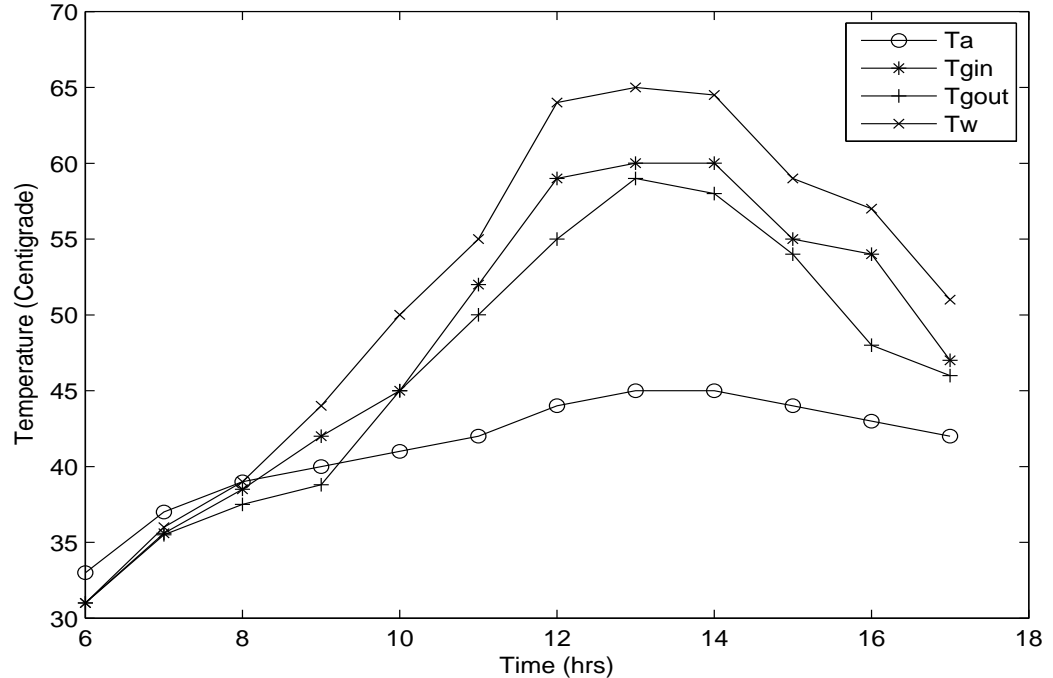


Figure 5.5: Hourly variation of various temperatures of still with cover slope angle 25° at local time

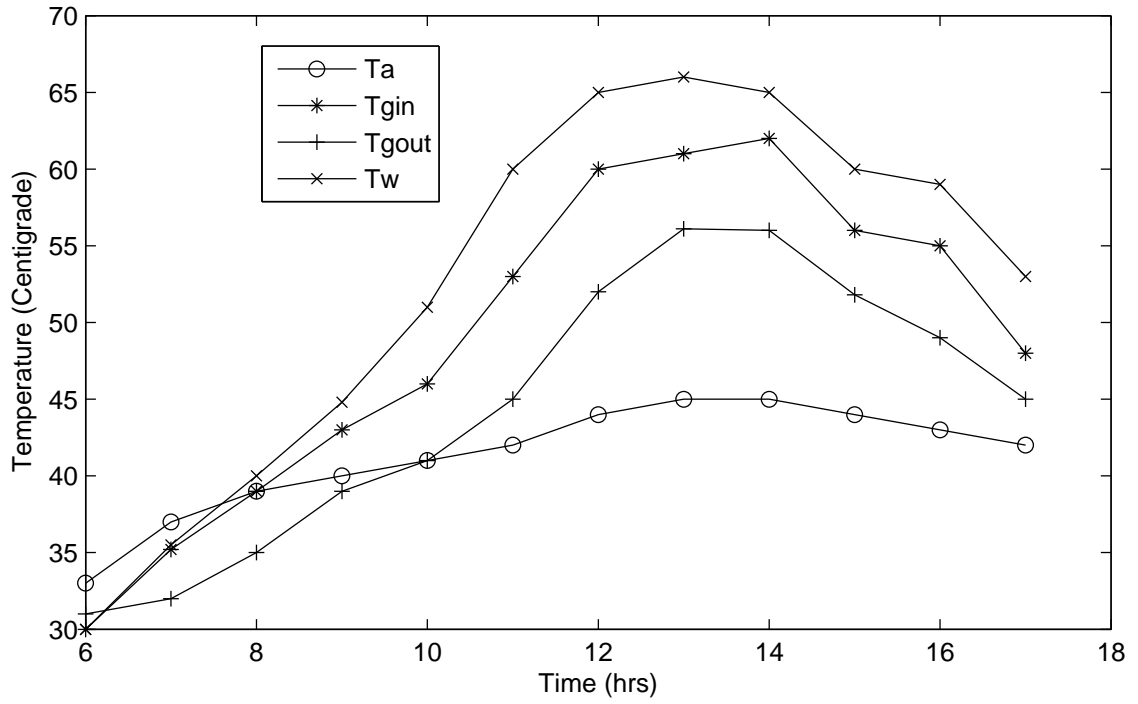


Figure 5.6: Hourly variation of various temperatures of still with cover slope angle 30° at local time

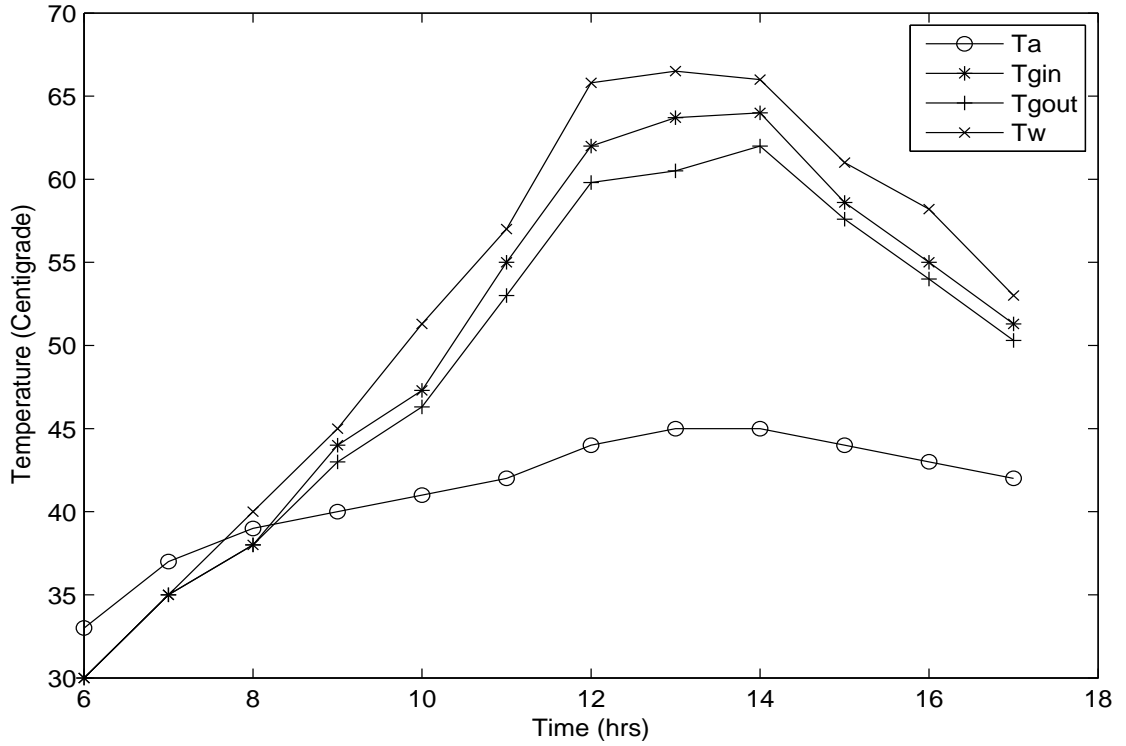


Figure 5.7: Hourly variation of various temperatures of still with cover slope angle 35° at local time

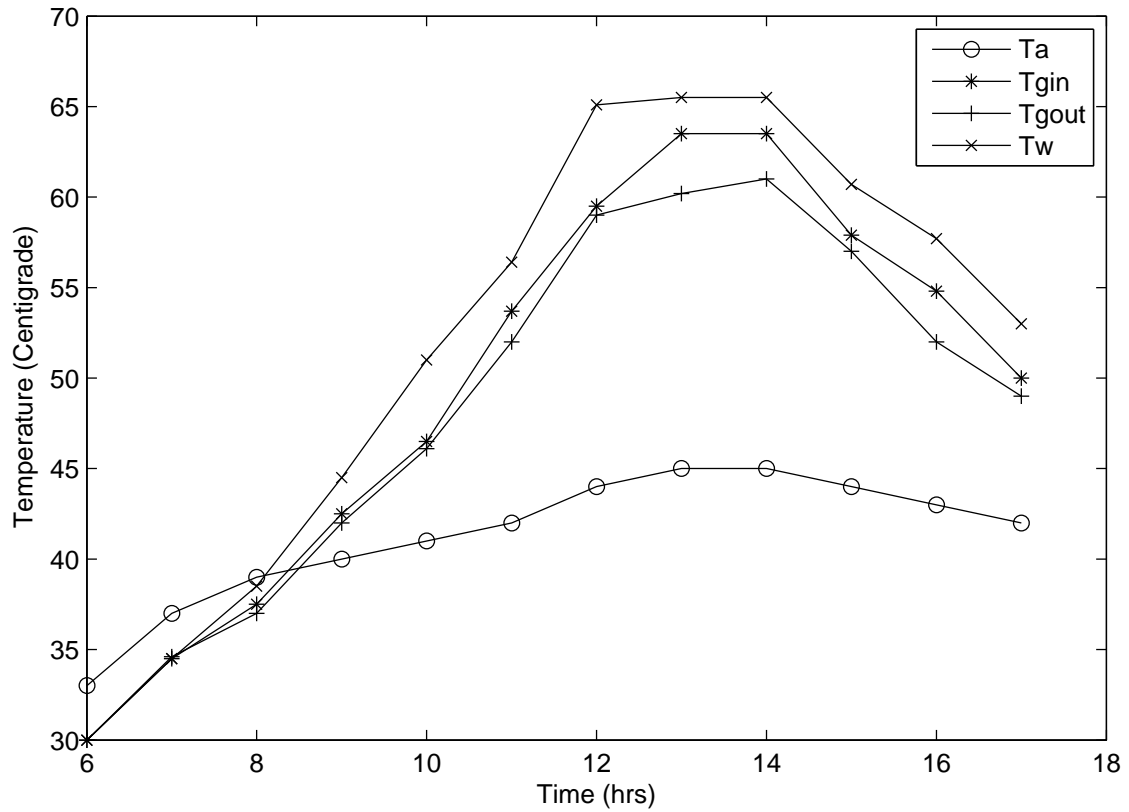


Figure 5.8: Hourly variation of various temperatures of still with cover slope angle 40° at local time

Similar trends of productivity and various temperatures (temperature of inner and outer glass surface and water temperature) for single slope solar stills with cover slope angles 25° , 30° , 35° and 40° were observed for water depths of 2cm and 3cm.

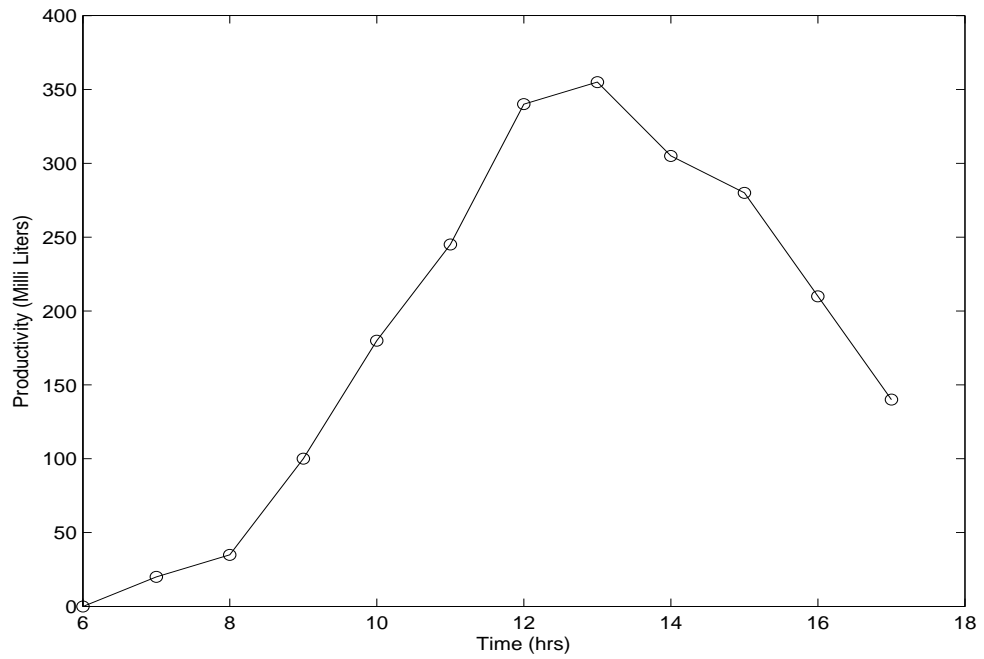


Figure 5.9: Hourly productivity of still with cover slope angle 25° with 2cm water depth in summer

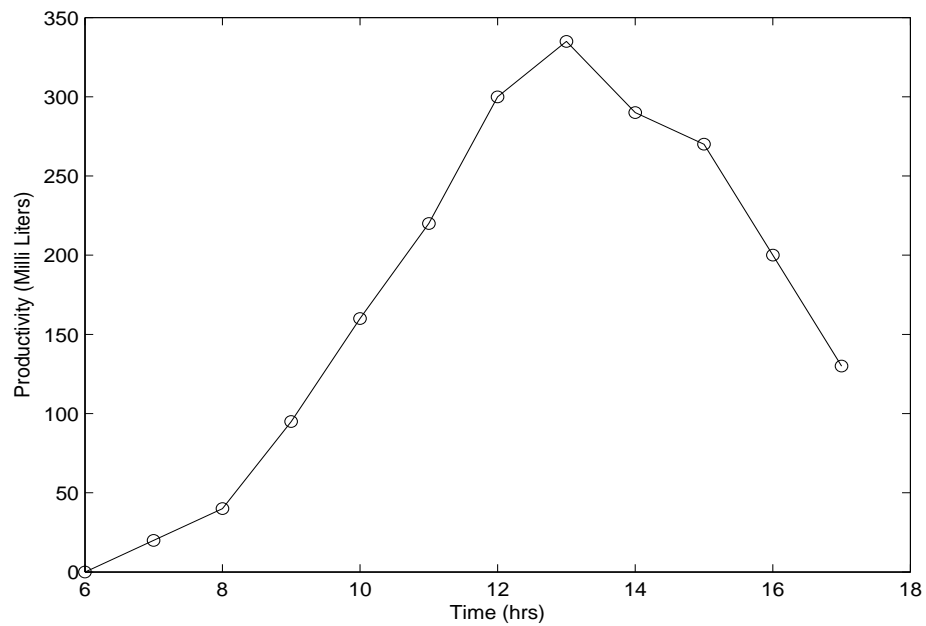


Figure 5.10: Hourly productivity of still with cover slope angle 30° with 2cm water depth in summer

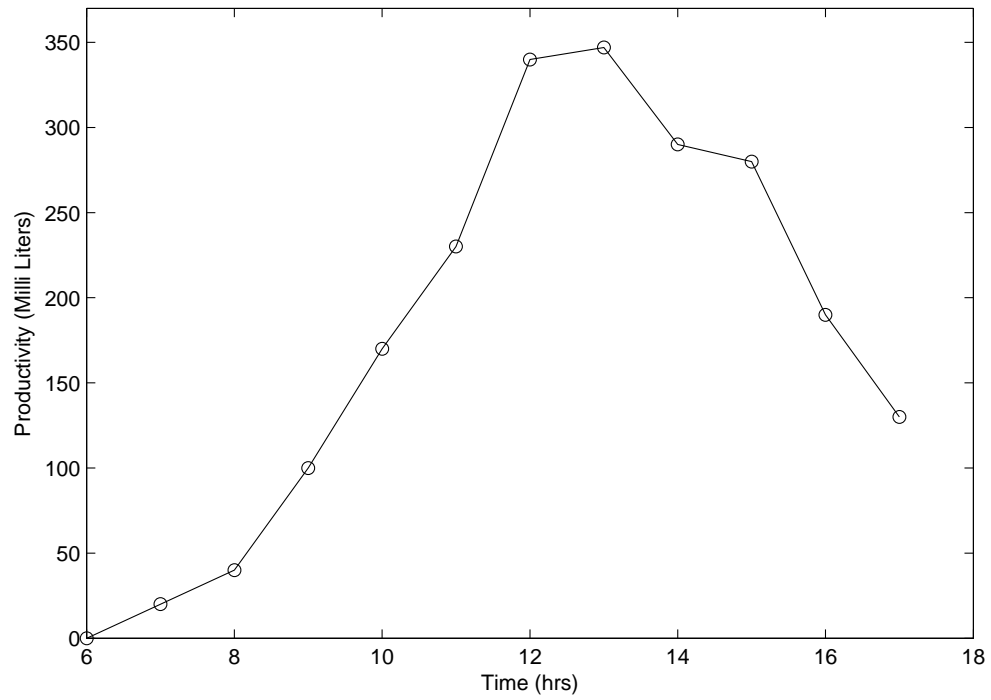


Figure 5.11: Hourly productivity of still with cover slope angle 35° with 2cm water depth in summer

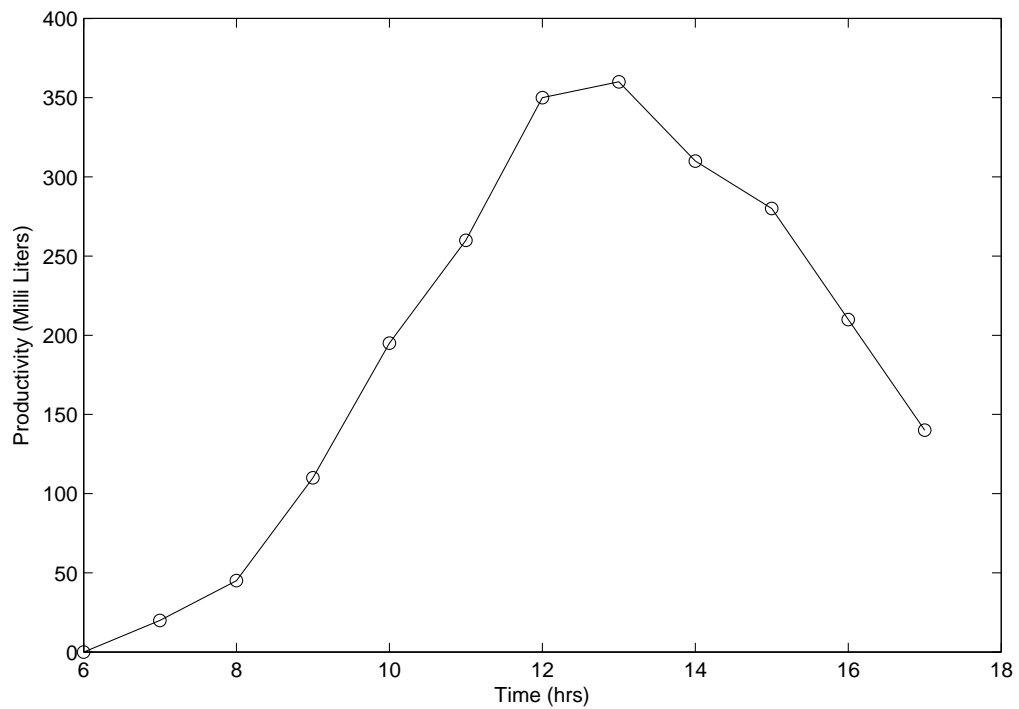


Figure 5.12: Hourly productivity of still with cover slope angle 40° with 2cm water depth in summer

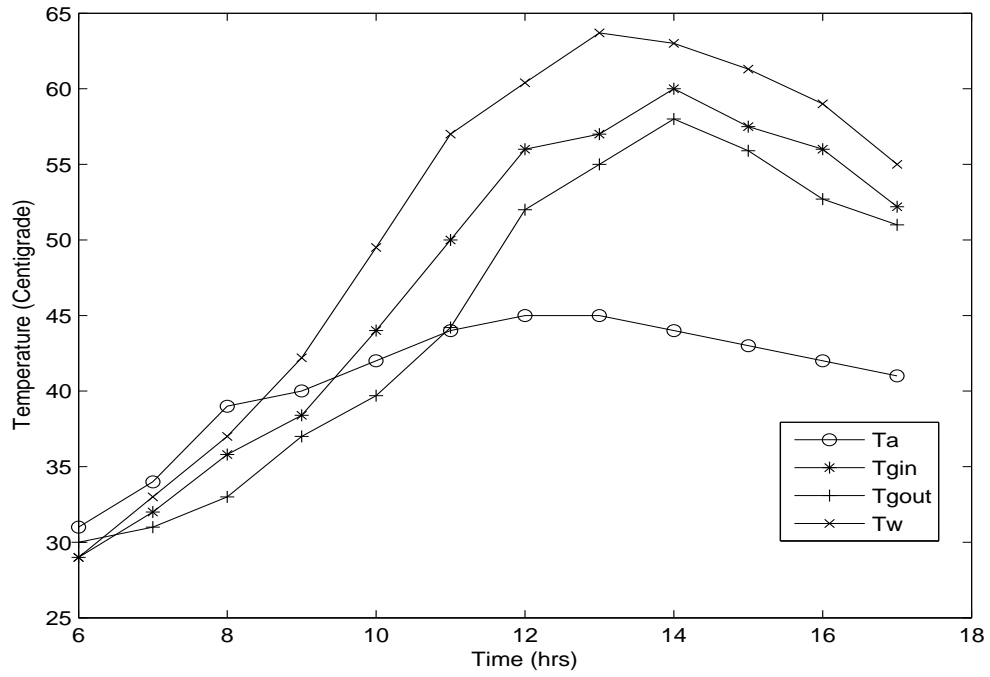


Figure 5.13: Hourly variation of various temperatures of still with cover slope angle 25° at local time

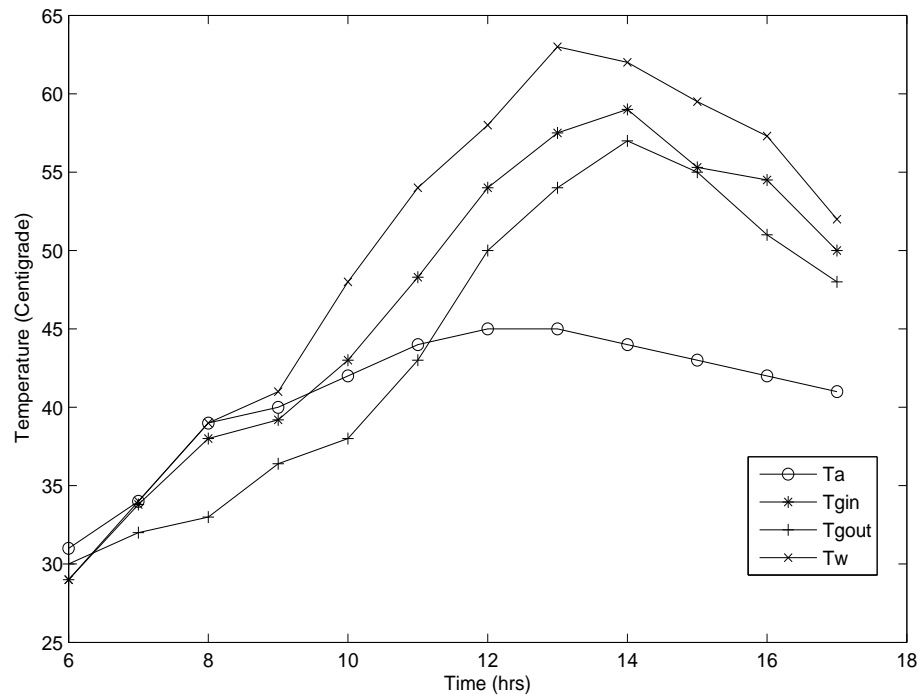


Figure 5.14: Hourly variation of various temperatures of still with cover slope angle 30° at local time

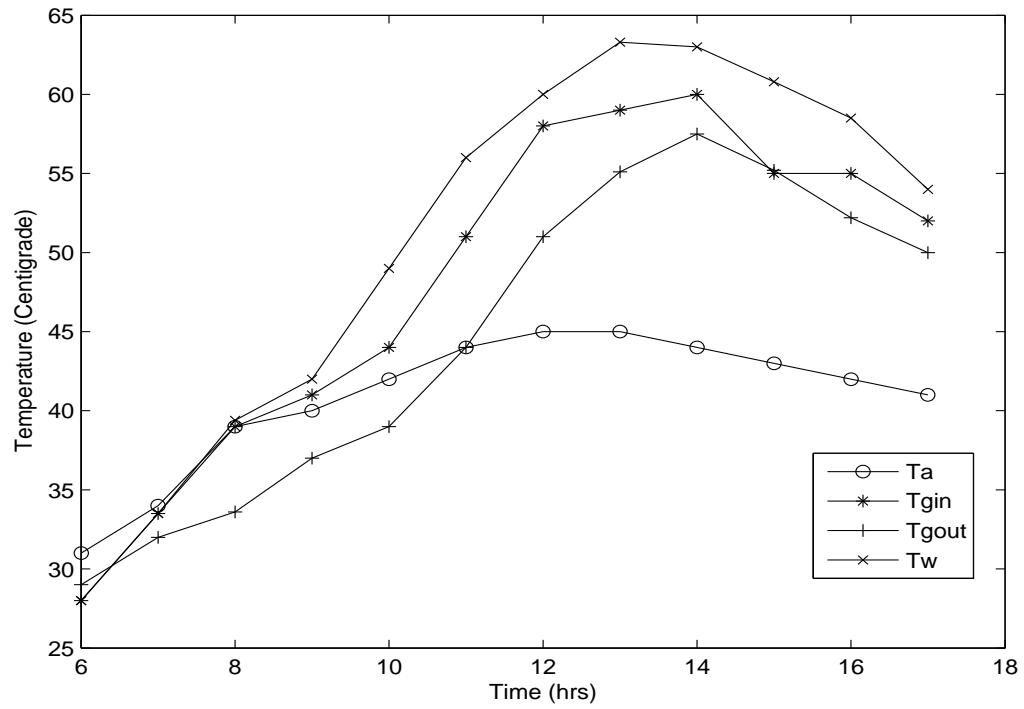


Figure 5.15: Hourly variation of various temperatures of still with cover slope angle 35° at local time

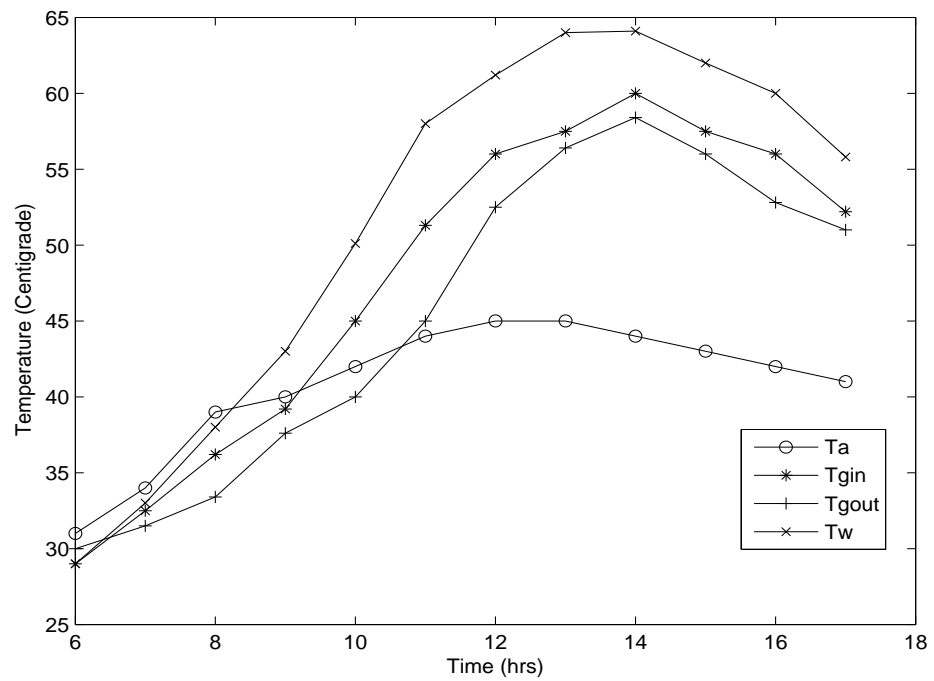


Figure 5.16: Hourly variation of various temperatures of still with cover slope angle 40° at local time

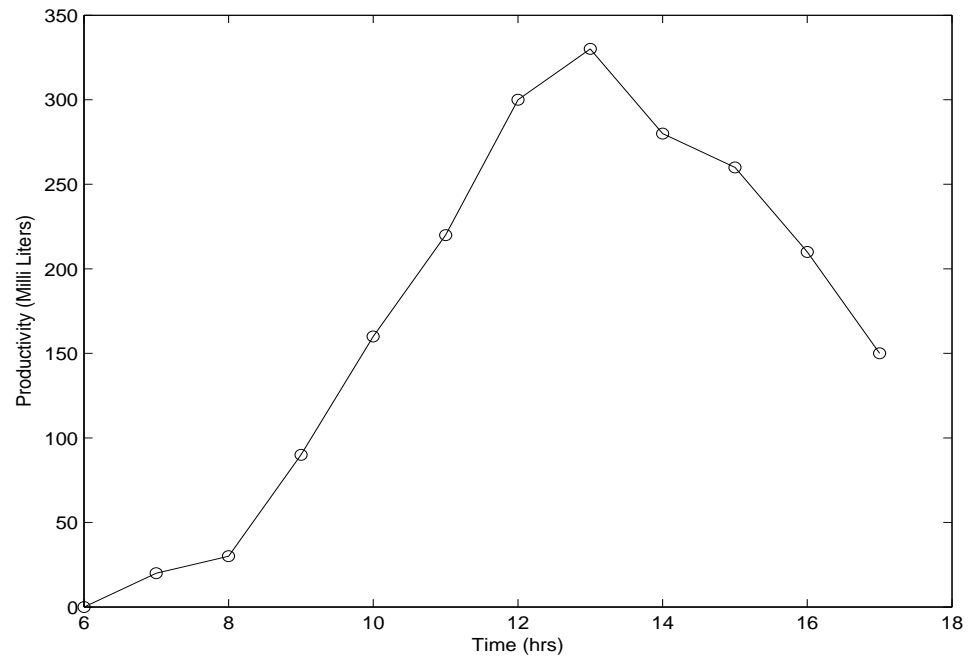


Figure 5.17: Hourly productivity of still with cover slope angle 25° with 3cm water depth in summer

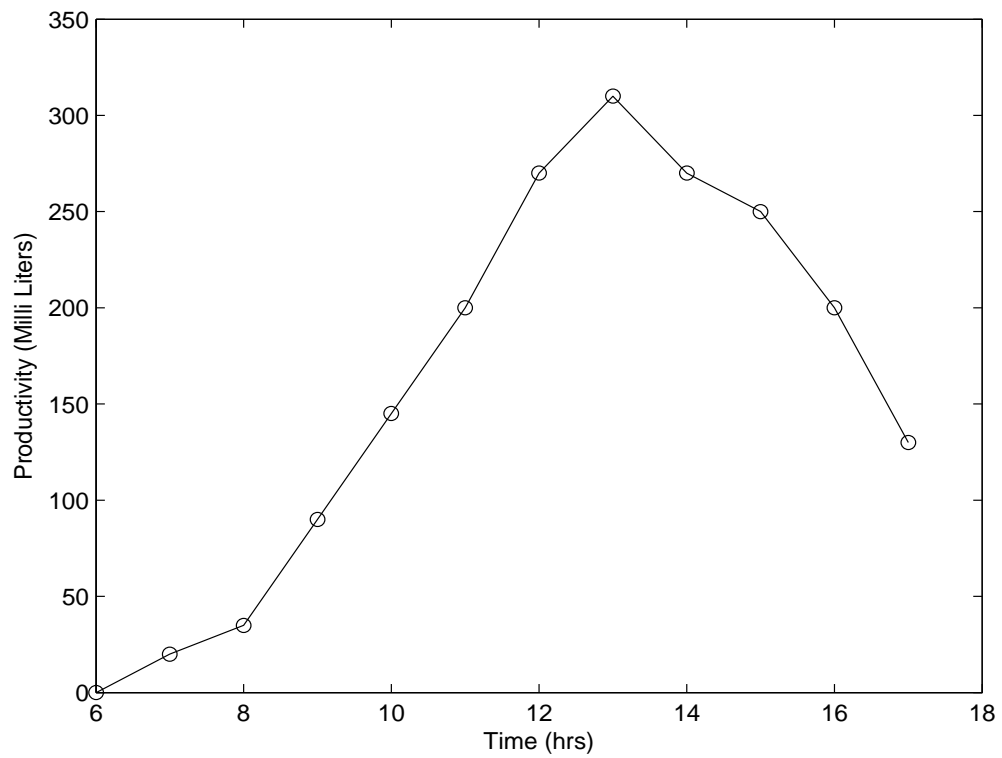


Figure 5.18: Hourly productivity of still with cover slope angle 30° with 3cm water depth in summer

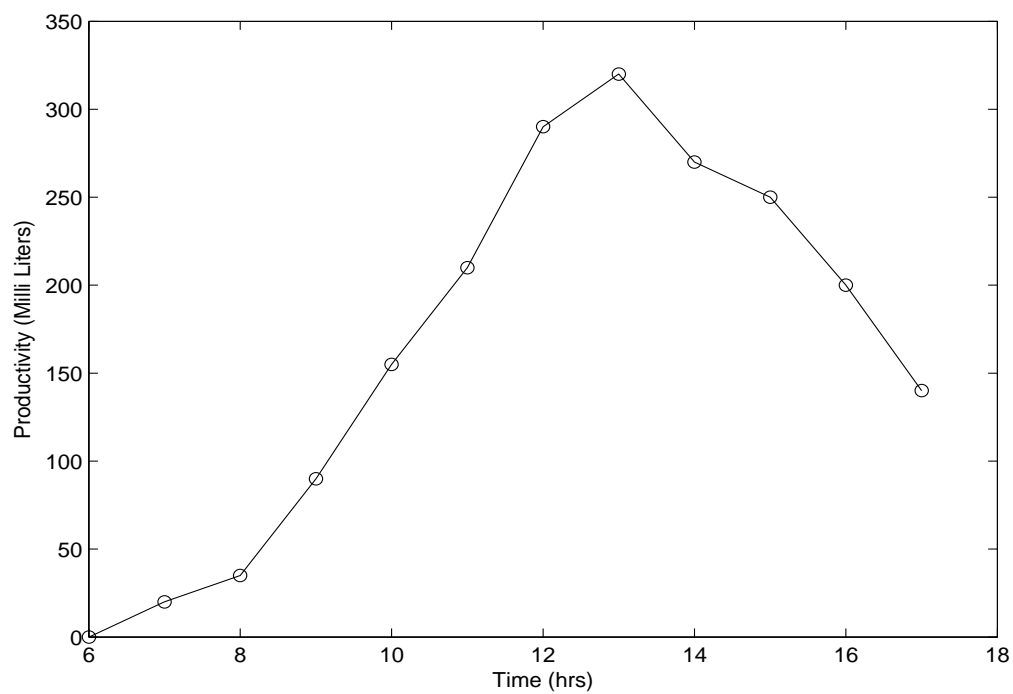


Figure 5.19: Hourly productivity of still with cover slope angle 35° with 3cm water depth in summer

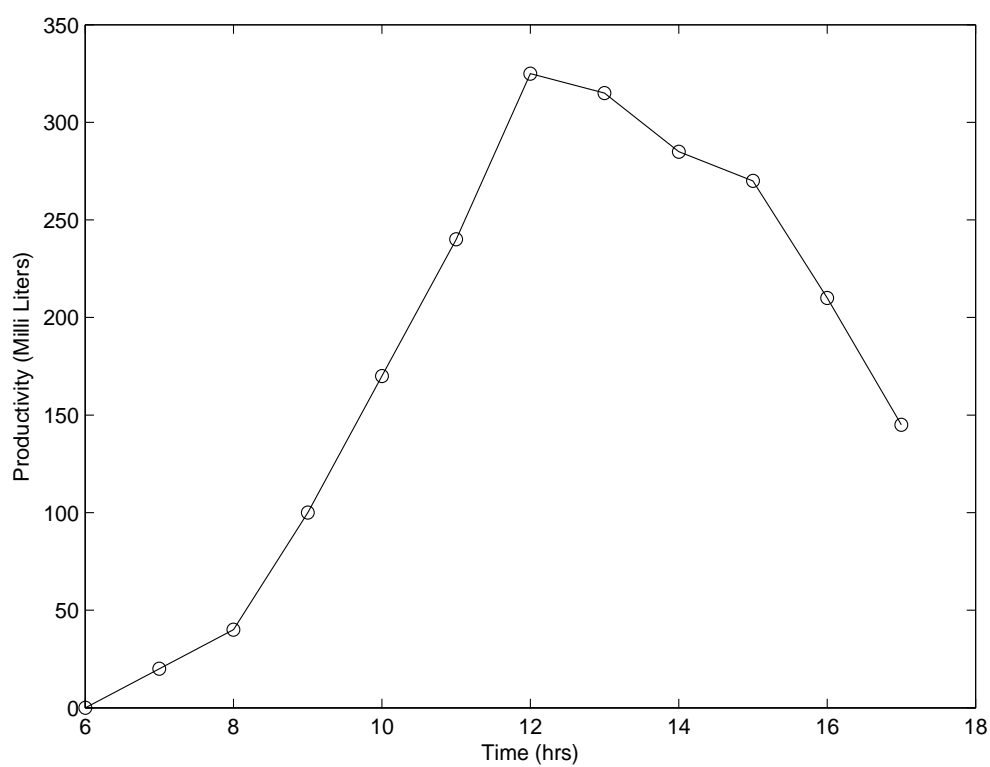


Figure 5.20: Hourly productivity of still with cover slope angle 40° with 3cm water depth in summer

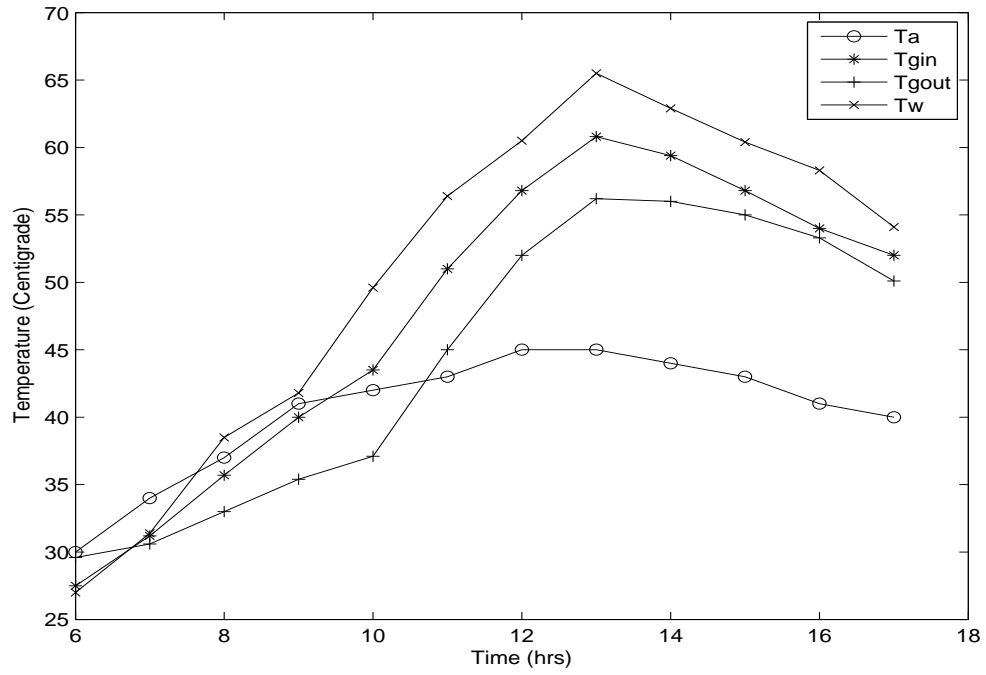


Figure 5.21: Hourly variation of various temperatures of still with cover slope angle 25° at local time

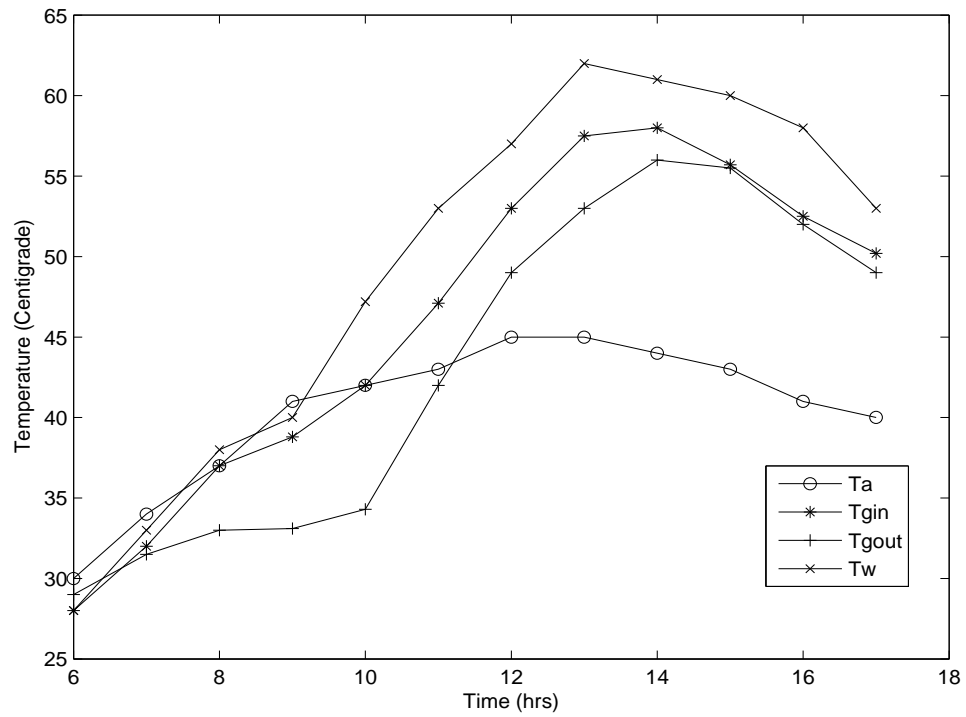


Figure 5.22: Hourly variation of various temperatures of still with cover slope angle 30° at local time

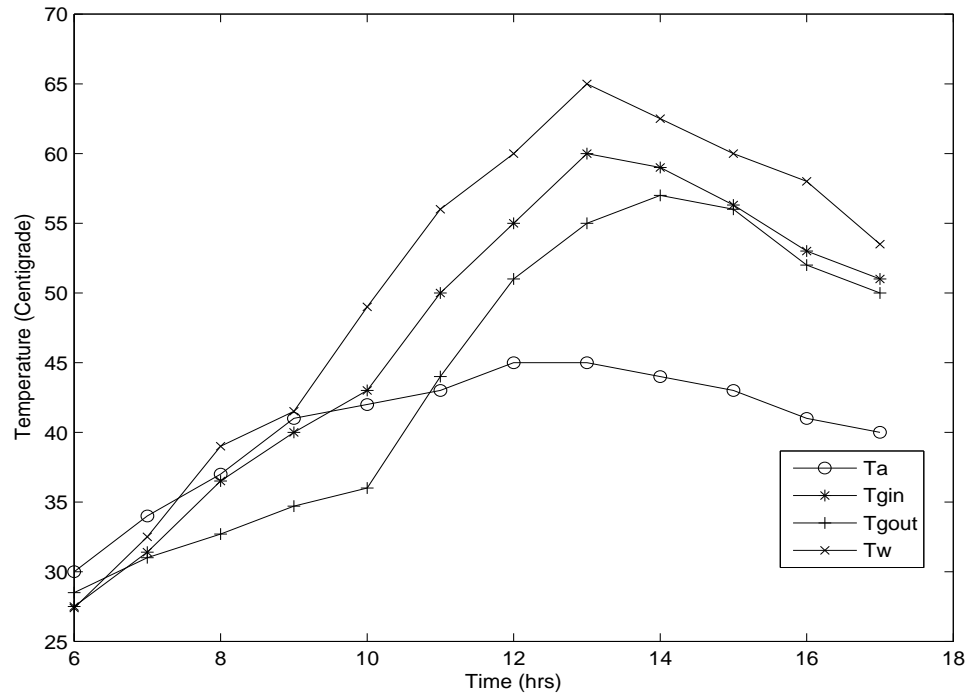


Figure 5.23: Hourly variation of various temperatures of still with cover slope angle 30° at local time

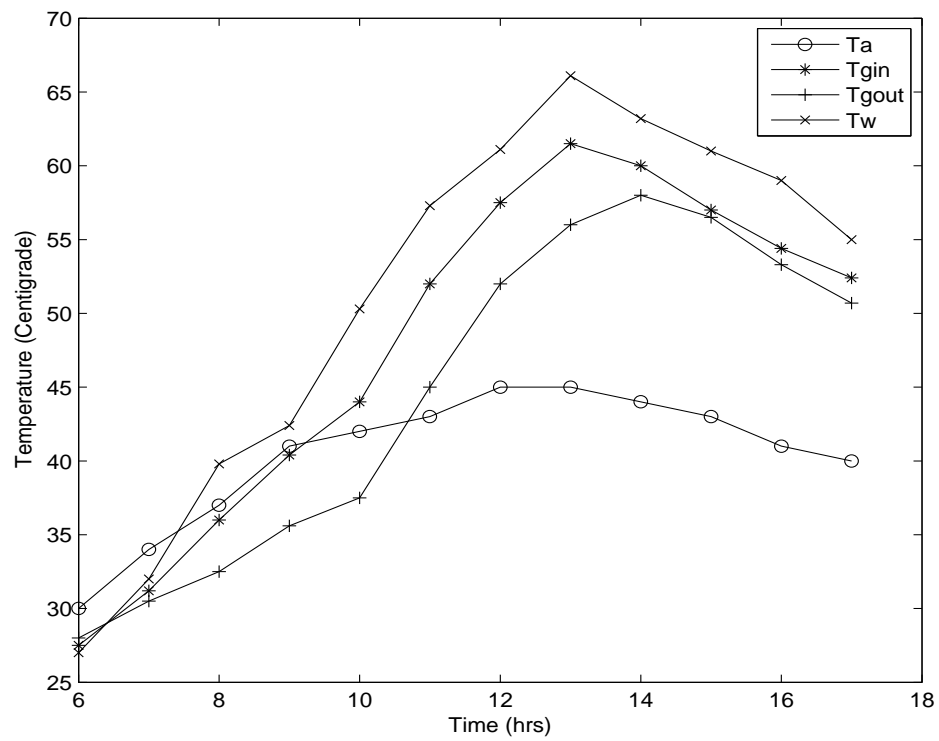


Figure 5.24: Hourly variation of various temperatures of still with cover slope angle 30° at local time

5.1 Effect of Cover slope angle

The productivity of the still increased from 25° to 35° cover slope angle and decreased for the angle of 40°. The maximum productivity of 2.42 liters was obtained from the solar still with a cover slope angle of 35°. The increase in productivity of 2.8% was observed for a change of angle from 25° to 30° and an increase of 10.9% was observed when the angle was changed from 25° to 35°. An increase of 6.8% was observed when the angle was changed from 25° to 40°. A decrease in productivity of 3.0% was observed when the tilt angle was increased to 40°.

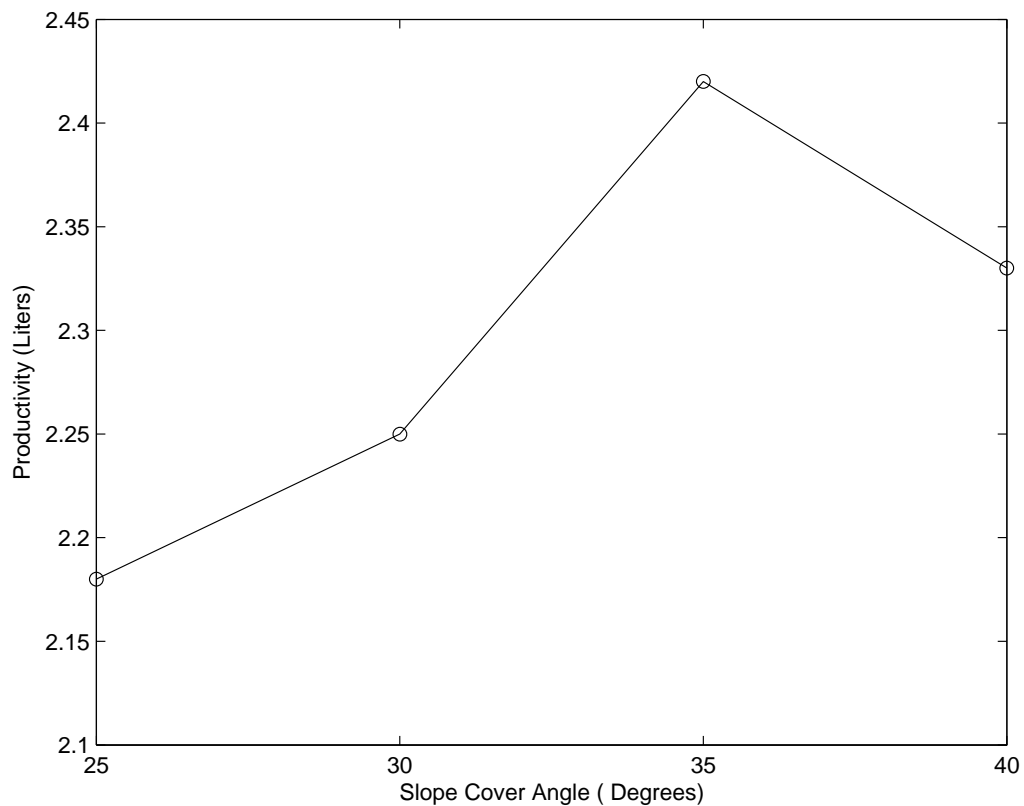


Figure 5.25: Productivity of Solar still for Summer

Figure 5.26, Figure 5.27 and Figure 5.28 respectively shows the variation of temperature of inner glass surface, temperature of outer glass surface and water temperature with respect to cover slope angles of the condenser cover 25° , 30° , 35° and 40° and water depth of 1cm.

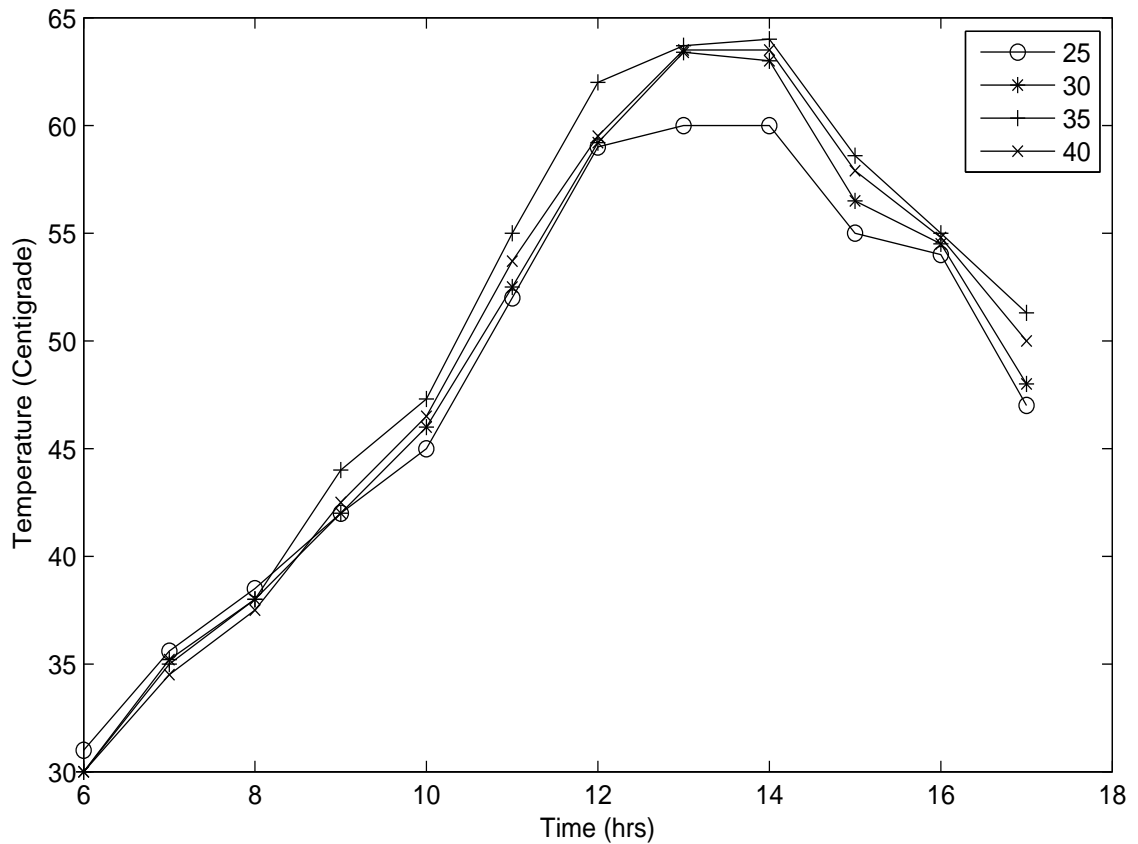


Figure 5.26: Temperature of inner glass surface for various cover slope angles at water depth of 1cm

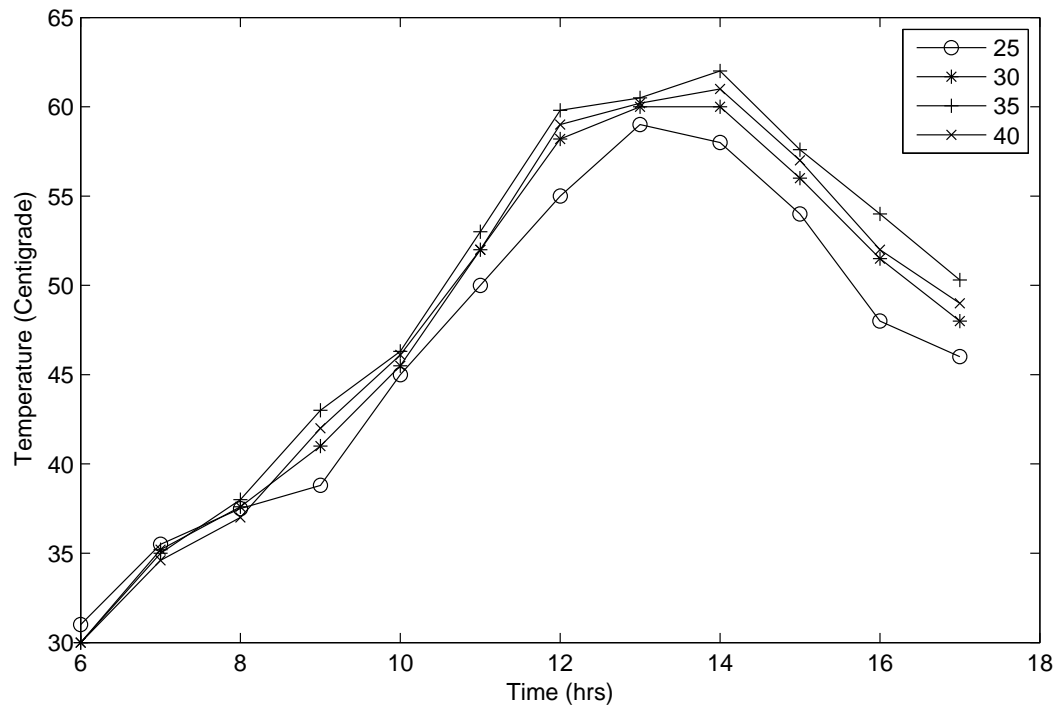


Figure 5.27: Temperature of outer glass surface for various cover slope angles at water depth of 1cm

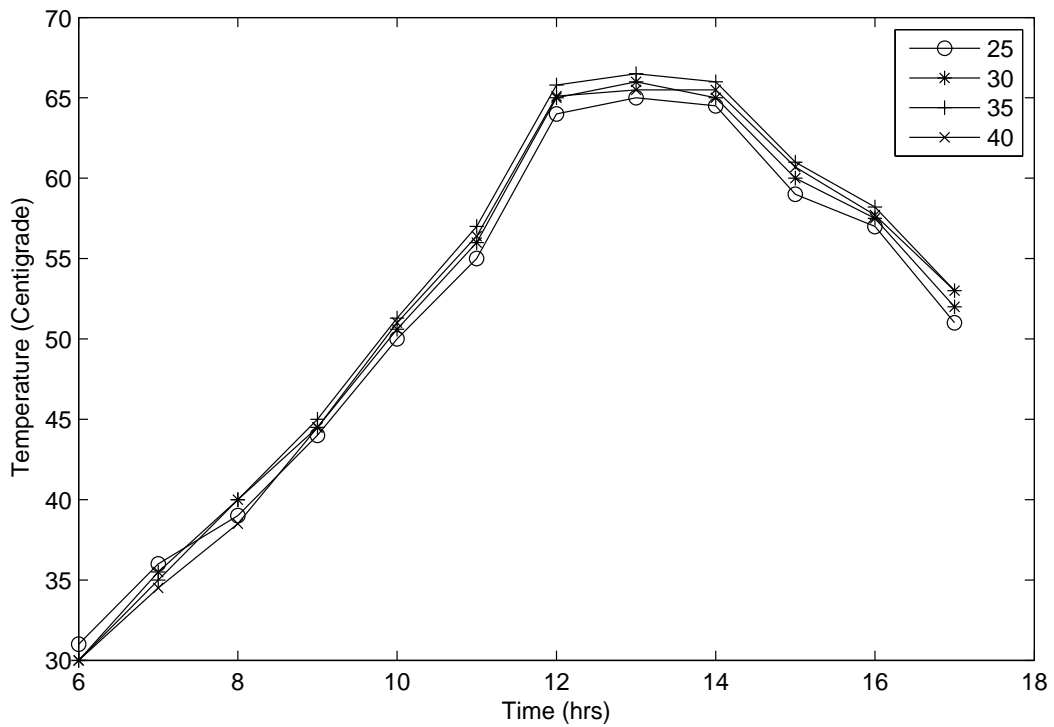


Figure 5.28: Temperature of water for various cover slope angles at water depth of 1cm

From Figure 5.26, Figure 5.27 and Figure 5.28 it can be observed that the inner glass surface temperature, outer glass surface temperature and water temperature in the early morning are maximum for the still with cover slope angle of 25° , showing maximum energy is received and hence the maximum productivity. At later hours of the day these temperatures are maximum for the still with cover slope of 35° , showing the increase in productivity compared to other stills. The same trend is observed at water depths of 2cm and 3cm.

5.2 Effect of Water depth

The performance of a single slope solar still was tested for three different water depths 1cm, 2cm and 3cm for a typical day in June as shown in Figure 5.29. As the water depth in the basin was increased from 1 cm to 3 cm, the productivity of the still decreased. Several researchers: Kumar et al., Kamal , Nafey et al. , Al-Hinai et al. , Dev and Tiwari and Akash et al. have found the same effect of water depth on productivity, i.e.; the shallower the water depth, the maximum will be the output. As the water depth increases, the heat capacity of the water increases and the time required to raise its temperature also increases, as it takes more time to release the stored energy. This results in a decrease in productivity for high water depths.

Considering all the water depths and the cover slope angles, the solar still with a 35° angle gave the best results. The productivity for the solar still with 25° decreased by 6.2% when the water depth was increased from 1 cm to 2 cm, whereas for a depth increase from 2 cm to 3 cm, a decrease of 7.3% was observed. The productivity for the solar still with 30° decreased by 5.3% when the water depth was increased from 1 cm to 2 cm,

whereas for a depth increase from 2 cm to 3 cm, a decrease of 7.9% was observed . The productivity for the solar still with 35° decreased by 6.1% when the water depth was increased from 1 cm to 2 cm, whereas for a depth increase from 2 cm to 3 cm, a decrease of 7.04% was observed. The productivity for the solar still with 40° decreased by 5.3% when the water depth was increased from 1 cm to 2 cm, whereas for a depth increase from 2 cm to 3 cm, a decrease of 7.8% was observed.

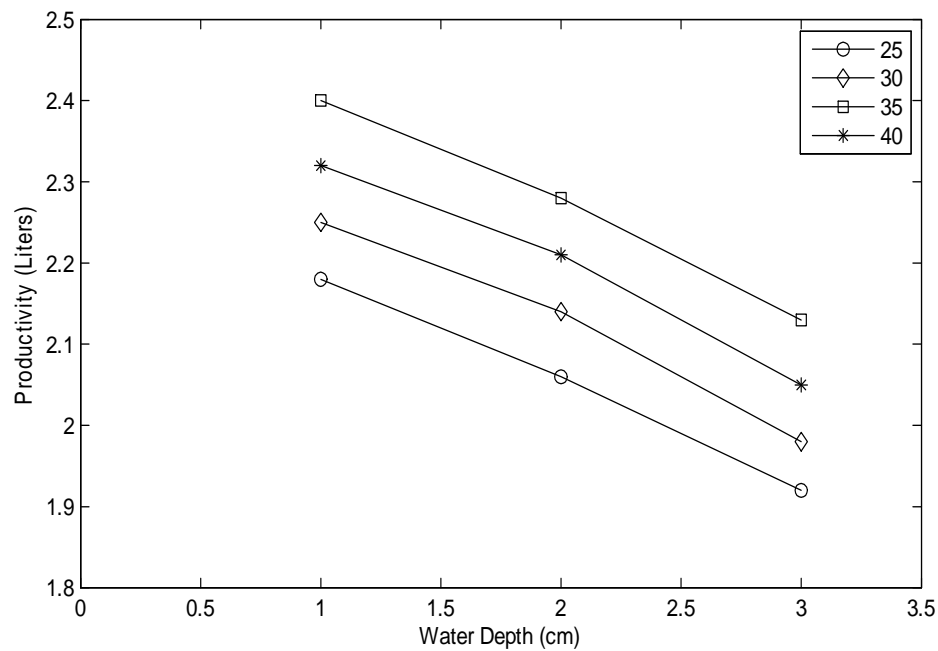


Figure 5.29: Productivity of stills with different water depth in Summer

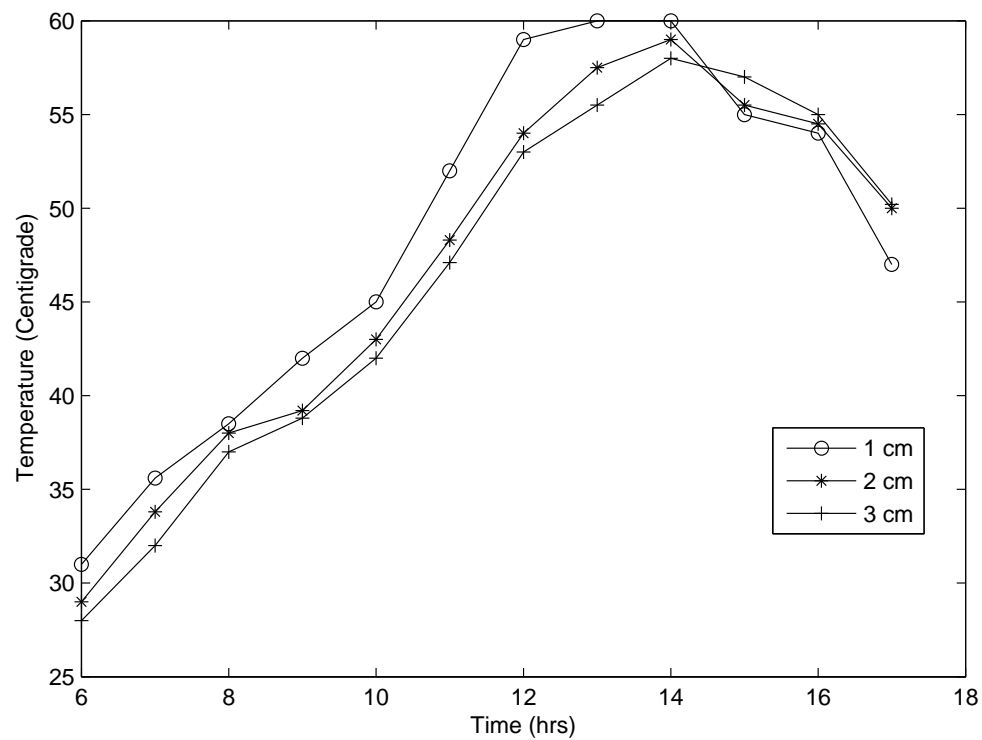


Figure 5.30: Inner glass temperature of a solar still with a cover slope angle of 25° at different water depths

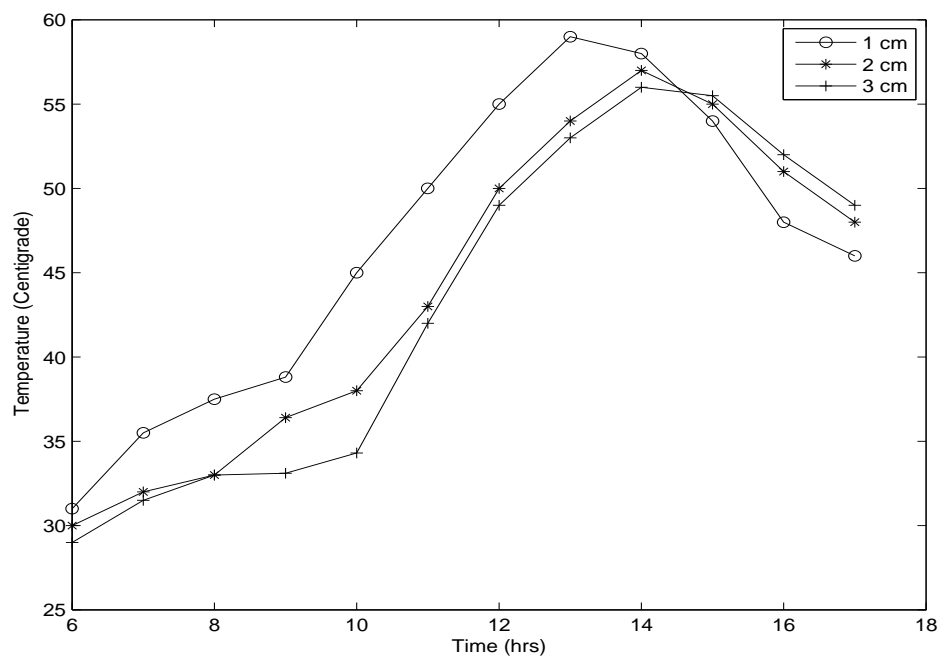


Figure 5.31: Outer glass temperature of a solar still with a cover slope angle of 25° at different water depths

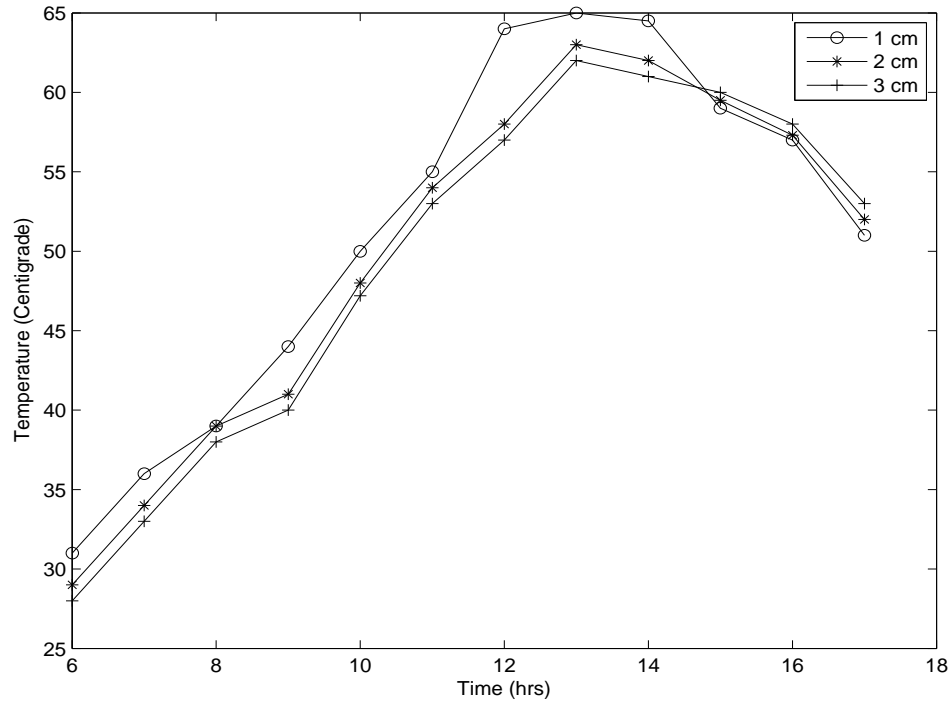


Figure 5.32: Water temperature of a solar still with a cover slope angle of 25° at different water depths

5.3 Effect of External reflectors

The optimized cover slope angle and water depth are 35° and 1cm respectively. In the second part of the experiment, effect of external reflectors on the productivity of optimized solar still is studied. The solar still with 35° cover slope angle is tested for a single day in the month of December. The productivity of 1.15 liters is obtained and the performance of the still is shown in Figure 5.33.

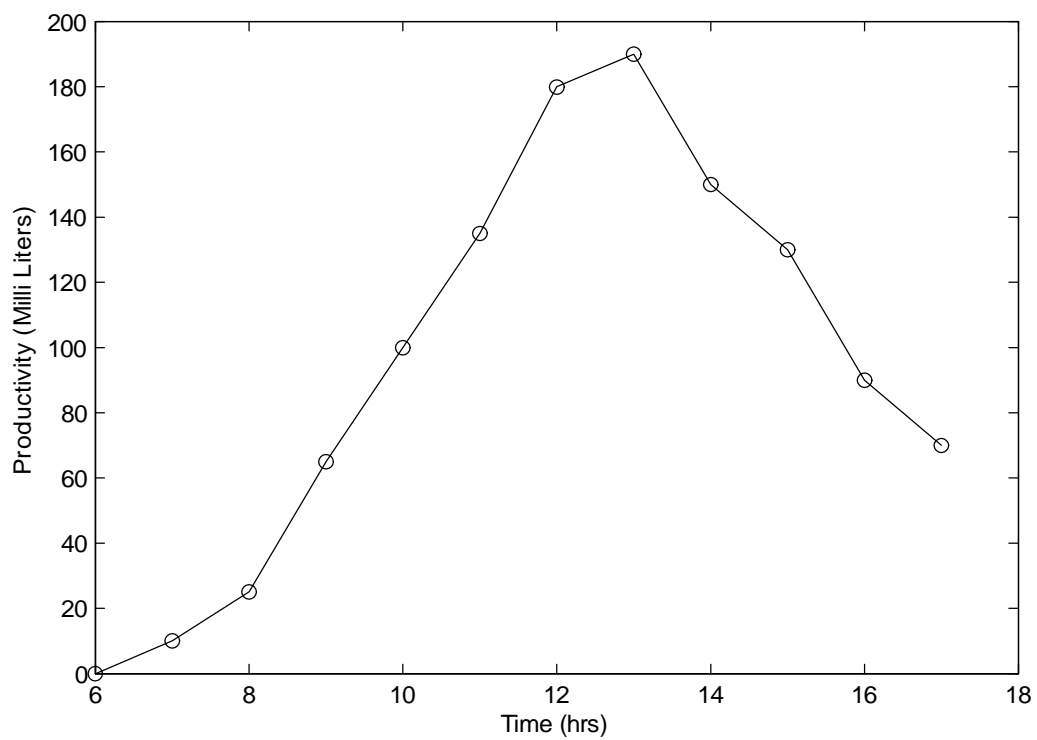


Figure 5.33: Hourly productivity of still with cover slope angle 35° with 1cm water depth in winter

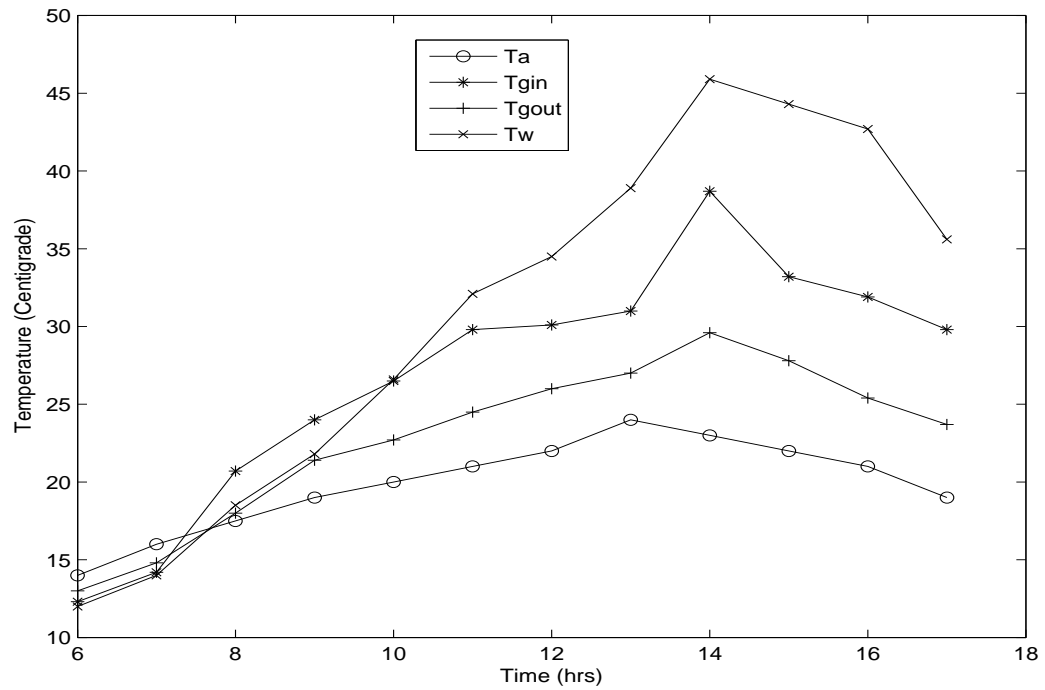


Figure 5.34: Hourly variation of temperatures for a cover slope angle of 35° and water depth of 1cm

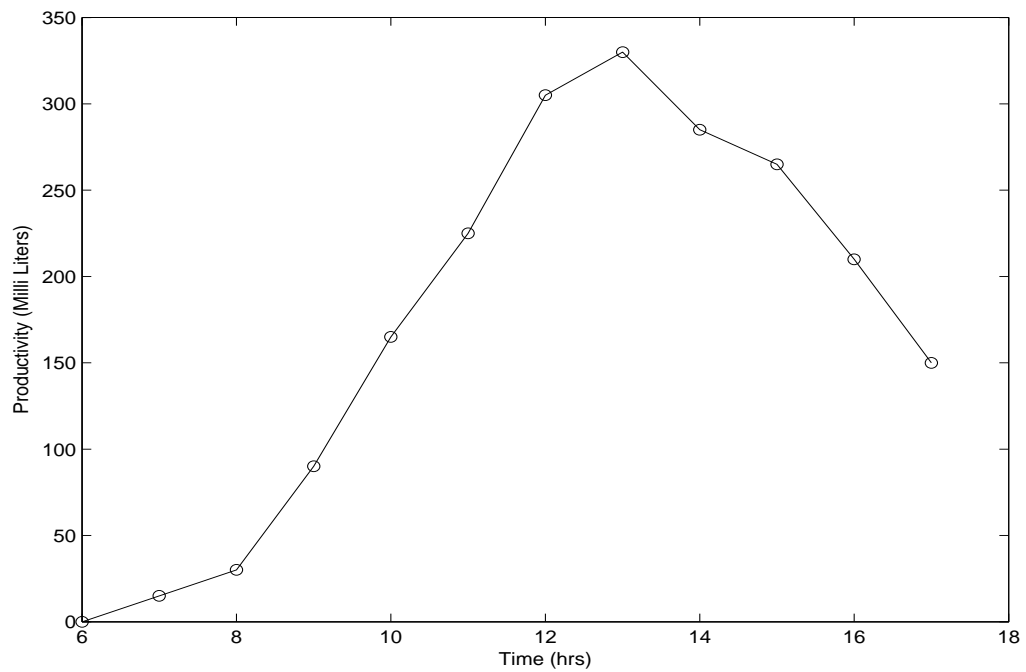


Figure 5.35: Hourly productivity of still with a cover slope angle of 35° and 1cm water depth with external mirrors in winter

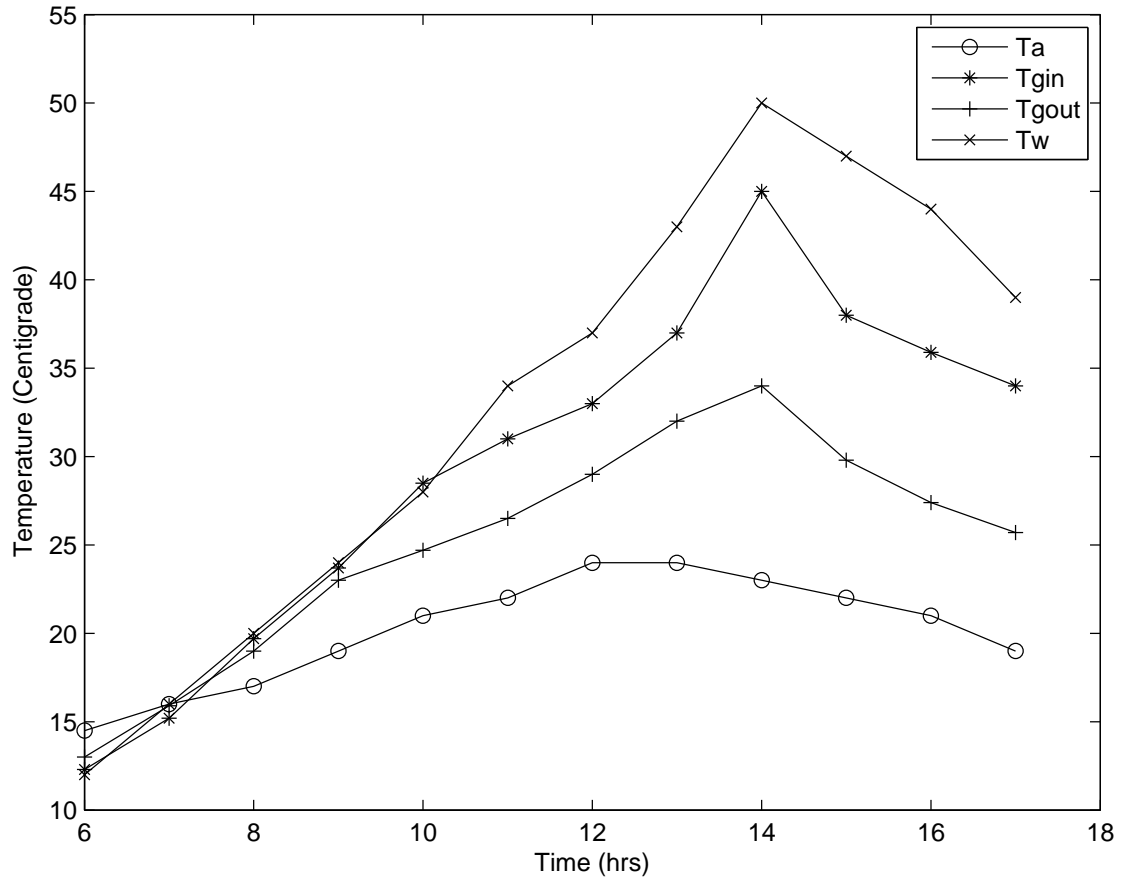


Figure 5.36: Hourly variation of temperatures of a solar still with a cover slope angle of 35° and water depth of 1cm with external mirrors

The productivity of a solar still with external mirrors, cover slope angle of 35° and water depth of 1cm is shown in Figure 5.35. The external reflector increased the amount of solar radiation falling on the solar still. An increase in productivity of 80% was obtained with the use of external mirrors. The hourly variation of inner glass temperature, outer glass temperature and water temperature are shown in Figure 5.36.

CHAPTER 6

CONCLUSIONS AND FUTURE RESEARCH

6.1 Conclusion

The work presented in this thesis focuses upon performance enhancement of single slope solar still. Existing methods in the literature to improve the productivity of the solar still has been studied. The following conclusions can be made based on the results obtained in the experiments.

The optimum glass cover tilt angle for best performance of a single slope solar still operating in Saudi Arabian climatic conditions (summer season) is 35° .

The optimum water depth for highest productivity in summer is 1 cm. Water depths below 1 cm are not recommended as a lot of brine accumulation in the basin is expected based on the experimental observations from this study.

The highest experimental productivity obtained on a typical day for summer is 2.42 liters.

The external reflectors which were used to concentrate solar radiation into the single slope solar still increased the productivity by 80%.

6.2 Summary

The contribution of this thesis can be summarized as follows:

- Four single slope solar still units (25° , 30° , 35° and 40°) were designed, fabricated and tested in an open ground in KFUPM campus, Dhahran ($26^\circ 16'N$ Latitude and $50^\circ 10'E$ Longitude). The experiments were carried out during summer season for optimizing best cover slope angle and water depth.
- The solar still with cover slope angle of 35° gave best results at the depth of 1cm. To increase the productivity in winter season four mirrors with the dimensions same as that of the basin of the still were used on four sides of the still. These mirrors reflected solar energy into the basin thereby improving the amount of solar radiation falling into it. This in-turn improved the performance by 80%.
- Several researchers used polished metal surfaces and mirrors as internal and external reflectors to improve the performance of the solar still and an increase in output of 30% to 70% was obtained.

A journal paper [76] has been submitted and a conference paper [77] has been accepted from this work.

6.3 Recommendations for Future Research

Following are some of the recommendations for future research:

- a) A thin glass cover can be used to improve the productivity by allowing more solar energy to pass into saline water in the still.
- b) Insulation material like glass wool etc., can be used to improve the efficiency of solar still by reducing the heat losses through the basin.
- c) Fins can be used on the outer surface to enhance the convection heat transfer to the atmosphere.
- d) Surface heating of water mass using black dye, rubber, sponge etc., increases rate of evaporation thereby increasing productivity.

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